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Measurements Made Aloft by a Twin-Engine Aircraft to Support the SCOS97-NARSTO Study

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

During the summer of 1997, the Southern California Ozone Study (SCOS97) was conducted to update aerometric and emissions databases and model applications for ozone episodes in Southern California and to quantify the contributions of interbasin transport to exceedances of the ozone standards in neighboring air basins. One of six SCOS97 sampling aircraft was a Piper Aztec. The Aztec performed northern-boundary measurements of aloft air quality and meteorology in the southern Mojave Desert and northern Los Angles basin. The aircraft also served as a backup for another SCOS97 aircraft that performed flights in the western part of the study domain. The Aztec data were reviewed to identify the occurrence and types of ozone layers aloft and to estimate the initial and boundary conditions in the Desert on the first day of Intensive Operational Periods (IOPs). Ozone carryover aloft was seen on all mornings in vertical spiral measurements in the Basin. Detached layers above the boundary layer were seen on about 20% of Basin morning and afternoon spirals. Offshore elevated ozone layers of up to 184 ppb were seen below 500 m. The morning ozone concentrations in the Desert ranged from 40 to 70 ppb and the NO_y concentrations ranged from 2 to 4 ppb, indicating relatively clean, but not pristine boundary conditions. These data are part of the SCOS97 data archive for use in further analysis and modeling.

ACKNOWLEDGMENTS

The work described in this report was funded by the California Air Resources Board (ARB). The Research Division of the ARB was responsible for administration of the contract, and Mr. Leon Dolislager was the ARB project officer.

The extra efforts of the ARB meteorology staff and the SCOS97 management team in preparing daily weather and pollution forecasts used during the program were greatly appreciated. In particular, Mr. Leon Dolislager and/or Mr. Bart Croes were in daily contact with the aircraft crew during the field program. Their knowledge, cooperation, suggestions, and dedication contributed greatly to the success of the program.

During an inter-comparison sampling flight with the University of California at Davis (UCD), Dr. John Carroll operated the UCD aircraft. His professionalism and extra effort contributed to an excellent set of data for the comparative purposes. During the inter-comparison flight with the U.S. Navy (Point Mugu), Mr. Roger Helvey coordinated the efforts of the Navy aircraft. We thank him also.

Mr. Kurt Bumiller of the University of California Riverside, College of Engineering, Center for Environmental Research and Technology (CE-CERT), under a subcontract to Sonoma Technology, Inc. (STI), performed most of the calibrations on the sampling instruments aboard the aircraft. His care, knowledge, and dedication contributed greatly to the results. In addition, he was responsible (through CE-CERT) for the distribution of sampling media used during the collection of grab samples and for retrieving the samples after they were taken.

We also wish to thank the following STI employees. Working as a part-time STI employee, Mr. David Wright was the primary instrument operator aboard the aircraft. He also provided backup calibration expertise. Dr. Beth Wittig compiled the data used to identify the locations and frequency of occurrence of elevated layers and to estimate the northern boundary concentrations on the first day of several episodes. Ms. Siana Hurwitt compiled the data for comparisons of aloft ozone measurements by the aircraft to surface ozone measurements. The efforts of each are greatly appreciated.

This report was submitted in fulfillment of ARB contract #96-309 entitled "Investigation of Processes Leading to the Formation of High Ozone Concentrations Aloft in Southern California" by Sonoma Technology, Inc. under the sponsorship of the California Air Resources Board. Work was completed as of March 18, 1999.

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EXECUTIVE SUMMARY

Background

From mid-June through mid-October, 1997, the Southern California Ozone Study (SCOS97) was conducted to update aerometric and emissions databases and model applications for ozone episodes in Southern California and to quantify the contributions of interbasin transport to exceedances of the ozone standards in neighboring air basins. One of six SCOS97 sampling aircraft was the STI Piper Aztec. During SCOS97, the Aztec performed aloft boundary condition measurements of air quality and meteorology in the southern Mojave Desert and northern Los Angles basin. The aircraft also served as a backup for another SCOS97 aircraft that performed flights in the western region of the study domain. The Aztec data were reviewed to identify the occurrence and types of aloft ozone layers and to estimate the Desert boundary conditions on the first days of episodes. These data are also part of the overall SCOS97 data archive for use in further analyses and modeling.

Methodology

Twenty-seven sampling flights were performed on 14 days. Real-time measurements included ozone, oxides of nitrogen (NO/NO_y), temperature, dew point, altitude, and position. A second NO/NO_y monitor measured NO_y minus nitric acid and aerosol nitrate. Separate sampling systems were used to collect integrated grab samples for subsequent hydrocarbon and carbonyl analysis. The NO/NO_y monitors and the ozone monitor were audited by the Quality Assurance Section of the ARB. Other quality control activities included extensive calibrations between flight days and intercomparisons with other aircraft and with surface monitoring stations.

The flights consisted of vertical spirals from 1500 to 2500 m msl to the surface at several locations with climbs or constant-altitude traverses between the spiral locations. Twenty-four flights were made between the base airports at Camarillo and Riverside, with early morning (0430-0900 PST) flights from Camarillo to Riverside and afternoon flights reversed. On five days the morning flight covered the Desert, and the afternoon flight was in the Basin. On seven other days the morning flight was in the Basin with four of the afternoon flights in the Desert and three in the Basin. On one day, a midmorning flight was made in Ventura County, and on two days, off-shore flights were made between Camarillo and San Diego.

Results

Ozone carryover aloft within the boundary layer was seen on all mornings during spirals in the Basin. The peak concentrations aloft averaged 48 ppb higher than at the surface, which averaged 16 ppb. This aloft ozone can increase surface concentrations when mixed down. The average aloft concentration (48 ppb + 16 ppb = 64 ppb) is higher than the clean-air ozone value of around 40 ppb, indicating carryover of ozone formed on prior days. However, this number is lower than expected when compared to the Desert boundary conditions and with prior examples of carryover in the Basin. On some days, however, the concentrations carried over exceeded 120 ppb. In the Desert, the average surface concentration was 41 ppb, with the peaks aloft averaging only 19 ppb greater than the surface concentrations. The aloft average, however, is 60 ppb, which is only 4 ppb less than the comparable average for sites in the Basin on (mostly) episode days.

Higher-elevation detached layers above the boundary layer were seen in the Basin on 17% of morning and 18% of afternoon spirals and were not observed in the Mojave Desert. When these layers were observed in the morning, they tended to be widespread. The most morning detached layers were seen over the San Gabriel Reservoir. This would be expected since that site is in a mountain canyon and would be subject to upslope and downslope flow and wind shear. The detached layers observed above the boundary layer were unlikely to have much of an effect on surface concentrations, except possibly in the mountains where they might impinge directly. The layers were typically less than 250 m thick and were over 1000 m above ground. They were in stable air, and entrainment to the surface would be difficult. If they were somehow entrained, they would be diluted by at least a factor of four. The exceptions to this generalization were the layers seen on August 7 during a Ventura County flight.

A midmorning August 7 flight extended from Van Nuys to Santa Barbara. Six of seven spirals showed high-concentration detached ozone layers peaking at over 1000 m msl. The layers were about 500 m thick. The seventh spiral, at Santa Barbara, had similar layers, peaking at 500 to 800 m msl. The peak layer concentrations ranged from 100 ppb to over 120 ppb. The layers were possibly transported from the SoCAB from the prior day, but the flight notes also indicated a contribution from a fire in the mountains north of Santa Paula. Because of the widespread nature and large vertical extent of the layers and the fact that nearby mountains extend higher than the layers, these layers may have contributed to surface concentrations later in the day, especially at inland and mountain locations where mixing could have brought the layers to the surface.

Several types of layering were seen in afternoon spirals. At El Monte, Ontario, Van Nuys, and the coastal sites, undercutting was frequently characterized by depleted ozone near the surface in the marine layer, with higher concentrations of older ozone remaining aloft under the subsidence inversion. At El Monte and the coastal locations, the undercutting is usually caused by the intrusion of the sea breeze, with higher humidities near the surface. At Van Nuys, the surface undercut layer sometimes had lower humidity than above, and may have been caused by some other windshear phenomena. Surface layers at all sites generally had higher concentrations of NO/NO_y than the layers above, indicating a contribution to ozone depletion from NO scavenging.

Another type of layer seen along the coast at Malibu and Camarillo was characterized by concentrations of ozone of up to 184 ppb at the top of the marine layer, with a sharp drop in dew point and ozone above. These layers were typically below 500 m and were at 200-300 m msl on the days with the highest concentrations. These layers may impact the shoreline mountains.

We examined afternoon desert spirals to detect transport to the desert on days when such transport would be expected. On August 6, transport was clearly contributing to concentrations exceeding the federal 1-h standard in the western Mojave Desert. On August 23, transport to the desert was not sufficient to cause the 1-h standard to be exceeded, but it might have contributed to exceedance of the new 8-h standard at some locations.

We examined morning desert flights on the first days of episodes to estimate boundary and initial conditions. The morning boundary ozone concentrations in the Desert ranged from 40 ppb to 70 ppb, the NO_y concentration ranged from 2 ppb to 4 ppb, and the NO_w concentration was about half the NO_y, indicating relatively clean, but not pristine boundary conditions.

Conclusions and Recommendations

Layering is a frequent occurrence in the Basin and must be accounted for in model initial conditions, and ideally should be reproduced by the models. From the aircraft data alone, it is not clear what effects these layers have on surface concentrations. However, useful analyses to answer this question can be envisioned by combining the full range of SCOS97 air quality and meteorological data available. Using simple analyses and more-sophisticated modeling, the aircraft data can be used to estimate the effect of the carry-over aloft ozone on surface concentrations. Such an estimate could be obtained by integrating the early-morning ozone concentration up to the midday and afternoon mixing heights to get an idea of the surface concentrations that would occur if the aloft ozone were mixed to the surface. A more refined way to perform such an analysis is to run a three-dimensional photochemical grid model with and without the measured initial carryover to assess the effect of carryover on surface concentrations.

1. INTRODUCTION

During the summer of 1997, the California Air Resources Board (ARB), the U.S. Environmental Protection Agency, and local air pollution control districts sponsored the Southern California Ozone Study (SCOS97). This study included upper-air air quality measurements by six aircraft. One of these, a Piper Aztec, was operated by Sonoma Technology, Inc. (STI) under a contract titled "Investigation of Processes Leading to the Formation of High Ozone Concentrations Aloft in Southern California." This report describes the STI measurements and operational details, discusses the causes of elevated layers, and provides summary information on the ozone layers seen during SCOS97 over the northern Los Angeles basin and southern Mojave Desert region.

The SCOS97 program is a component of the North American Research Strategy for Tropospheric Ozone (NARSTO); and the joint program is known as SCOS97-NARSTO. Details and objectives of the overall SCOS97-NARSTO study are described in the "Field Study Plan" (Fujita et al., 1996).

During the SCOS97 sampling program, the STI Aztec performed boundary condition measurements of aloft air quality and meteorology in the northern regions of the SCOS97-NARSTO study domain, including the southern Mojave Desert and northern Los Angeles basin. The aircraft also served as a backup aircraft for other SCOS97-NARSTO flights that were to be performed in the western region of the study area.

Real-time or continuous measurement data collected during STI sampling flights have been processed, edited, and reported to the ARB in a three volume data report titled "The Real-Time Measurement Data Collected Aboard the STI Aircraft During SCOS97 Sampling" (Anderson et al., 1998). The data report details the sampling that was performed and displays plots of the data collected by the continuous (real-time) sensors aboard the aircraft. Magnetic media copies (CDs) of the final processed data set were also delivered to the ARB as part of the data report.

Integrated grab samples for volatile organic compounds (VOCs) and carbonyl analyses were collected during most flights. Details of the collection of these samples were included in the data report. The grab samples were delivered to other contractors who were responsible for analyzing the samples and reporting the analytical results.

2. OVERVIEW OF THE STI AIRBORNE SAMPLING PROGRAM

As part of SCOS97-NARSTO, aloft air quality/meteorological measurements were performed within the study area shown in **Figure 2-1** by six different aircraft. The San Diego County Air Pollution Control District (SDCAPCD) operated a Piper Navajo and a Cessna 182. The University of California at Davis (UCD) also operated a Cessna 182. A Partnavia was operated by the U.S. Navy (Point Mugu). The California Institute of Technology (Cal Tech) operated a modified Cessna 337 called the Pelican. This report details the operations associated with the sixth aircraft, the STI Piper Aztec.

2.1 PROGRAM OVERVIEW

The primary objective of the STI airborne sampling program was to provide data to be used to investigate the processes that result in the formation of high ozone concentrations in layers aloft and to estimate the effect of those layers on surface concentrations at later times. The data analyses are not part of this contract.

A second objective was to support SCOS97-NARSTO by providing boundary condition measurements of aloft air quality and meteorology in the northern and eastern regions of the study domain, including the Mojave Desert.

In addition to these objectives, the project aircraft was called on twice to serve as a SCOS97-NARSTO backup aircraft for flights over the ocean in the western region of the study area.

The project aircraft shown in **Figure 2-2** was based at the Camarillo airport from June 7 through October 19, 1997. A satellite base of operations was maintained at the Riverside airport. The on-site crew consisted of a pilot and instrument operator. The aircraft program manager traveled to Camarillo during sampling episodes and returned to STI's home office during non-flight periods.

A total of 27 sampling missions (flights) were performed on 14 days. Inter-comparison flights with the UCD (July 8, 1997) and the U.S. Navy (September 30, 1997) aircraft were also performed. Thus, the Aztec flew a total of 29 flights.

Real-time measurements made aboard the aircraft included ozone, high-sensitivity NO/NO_y, temperature, dew point, altitude, and position. Separate sampling systems aboard the aircraft were used to collect integrated grab samples for subsequent VOC and carbonyl analysis. During SCOS97, a total of 78 VOC samples and 81 carbonyl grab samples were collected with the Aztec.

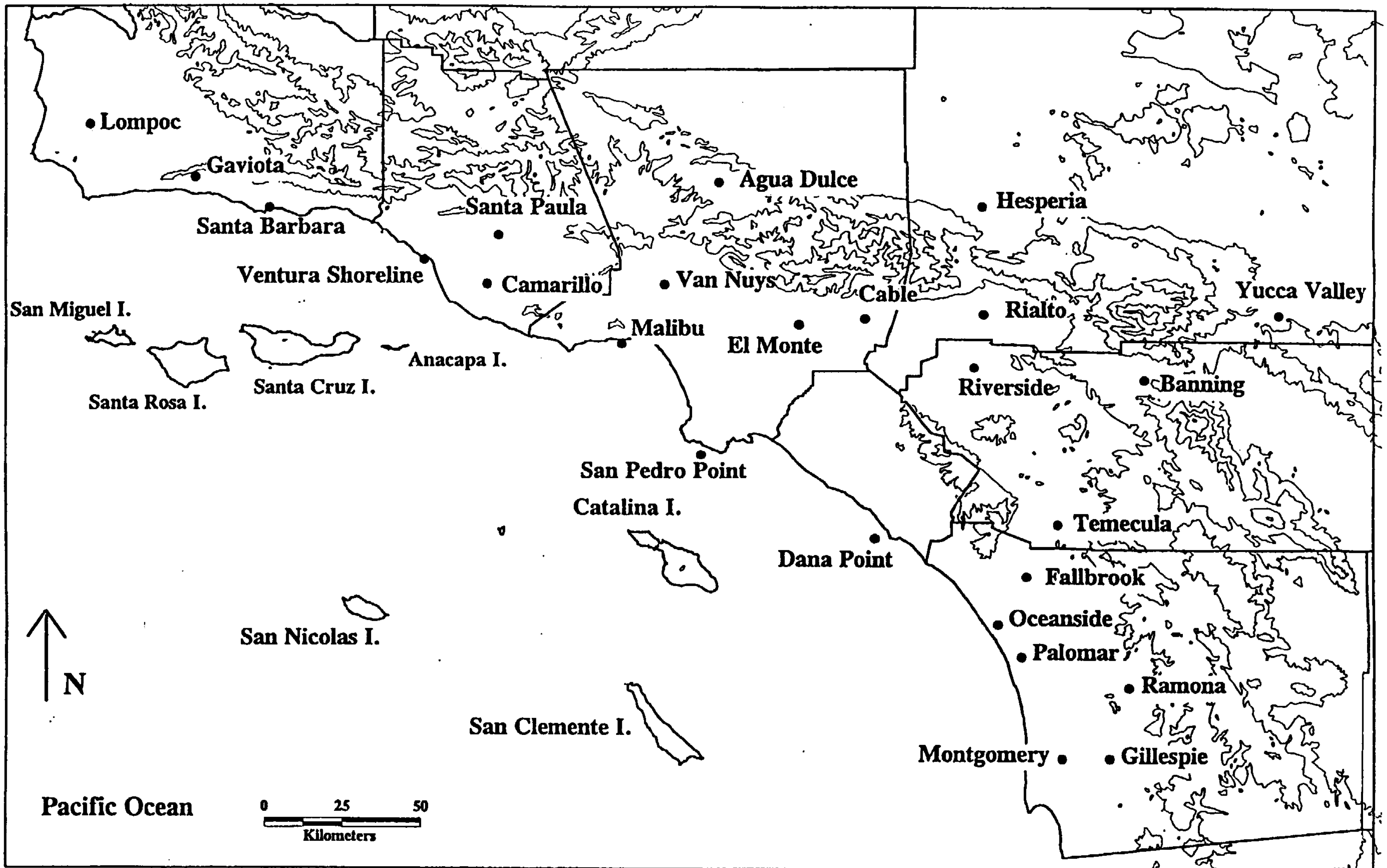

Figure 2-1. The SCOS97-NARSTO aircraft sampling domain.

Figure 2-2. The STI Piper Aztec used during the SCOS97 sampling program.

The NO/NO_y monitors and the ozone monitor operated aboard the aircraft were audited by personnel from the Quality Assurance Section of the ARB. The audit was performed before the start of sampling activities on June 9 and 10, 1997. The same monitors were subjected to a comparison check by the University of California Riverside, College of Engineering, Center for Environmental Research and Technology (CE-CERT) on October 17, 1997 after completion of the sampling program. Preliminary results were reported to STI by the ARB audit team and CE-CERT. Final audit results received from the ARB in January 1999 indicated no changes from previously reported preliminary results. The results indicated the instruments were operating normally, and were well within quality assurance (QA) control limits established by the ARB.

After ARB audits had been completed on both the STI and UCD aircraft, the two aircraft performed an inter-comparison flight near the El Monte airport. As part of the inter-comparison, CE-CERT released and tracked an ozonesonde from the El Monte airport while the two aircraft spiraled upward at the same location. Each group processed their own data and delivered the processed data to Desert Research Institute (DRI). DRI's review of these data was reported by Fujita et al., 1998.

Another inter-comparison flight was made with the Navy Partnavia near Camarillo on September 30. The STI data from the inter-comparison flight with the U.S. Navy aircraft were processed and delivered to the ARB. At the time of this report, the Navy's data were not available for comparison.

Prior to the start of the sampling program, STI developed sets of "strawman" flight plans for the operations of the four core aircraft (the Navajo, both Cessna aircraft, and the Aztec). STI gathered input from an ad hoc committee charged with designing flight plans, other SCOS97-NARSTO participants with interests in flights in their districts, and from modelers with an interest in the data. These preliminary flight plans were reviewed by the interested parties and were then modified to best meet the sampling objectives. Finalized plans were approved by the ARB and distributed to the participating flight groups.

Due to the number of project aircraft expected to be operating together within the sampling area, the uniqueness of their operations, and the volume of other aircraft activities within the sampling area, the cooperation and assistance of the Federal Aviation Administration (FAA) was needed. STI coordinated this effort before the start of field operations. The FAA assigned a member of the Southern California Air Traffic Control division (SoCal TRACON) to coordinate the activities of the research aircraft. Prior-day notification of upcoming flights was requested by SoCal TRACON. The STI aircraft program manager briefed the FAA prior to each flight day. SoCal TRACON then notified and coordinated all affected control agencies concerning the operations of all project aircraft.

The SCOS97 Field Program Management Committee (FPMC) was responsible for the selection of intensive operating periods (IOPs). Tentative notification of an upcoming IOP was posted for program participants by recorded phone message and e-mail two days before anticipated sampling was to start. The IOP status was reviewed and updated the morning before an IOP, with a final "GO NO-GO" decision posted the afternoon prior to the IOP start. Participants acknowledged receipt of sampling decisions by leaving a recorded message in return. Phone contact between the ARB and aircraft personnel also confirmed the choice of sampling routes that would be flown each day.

Instruments aboard the aircraft were calibrated the night before the start of an IOP. When the aircraft returned after a day of sampling, the instruments were calibrated again. This routine was performed each day of an IOP.

On a typical sampling day, the aircraft would depart from the Camarillo airport at about 0430 Pacific Standard Time (PST). It would sample along a pre-selected route through the northern region of the study domain. Regardless of which route was flown, the flight would end at the Riverside airport. In the afternoon, the aircraft would depart from the Riverside satellite base between 1300 to 1400 PST and sample along the northern portion of the study area using a different route from the morning flight. The afternoon flight would end back at the Camarillo airport.

When the aircraft landed at Riverside, the carbonyl grab sample bags and VOC sample canisters were retrieved by CE-CERT personnel and returned to the CE-CERT laboratory for eventual distribution to other contractors. The flight crew would notify the aircraft program manager by phone that they had landed. They also relayed information concerning what they had seen during sampling to the STI program manager. This debriefing normally occurred about 0830 PST. Whenever possible, the STI program manager would relay this preliminary information by phone to SCOS97 personnel at ARB for review and planning purposes.

When the aircraft returned to Camarillo at the end of the day, the fight crew was again debriefed. Data discs from the aircraft were copied and flight notes verified. Again, CE-CERT personnel retrieved the carbonyl grab sample bags and VOC sample canisters. Data processing was initiated and preliminary reviews of the data were performed during the evening hours. Interesting sections of data were plotted and forwarded to SCOS97 personnel at ARB.

Processing of the real-time continuous data collected during the sampling flights was continued at the STI facilities in Santa Rosa. A three-volume data report (Anderson et al., 1998) was delivered to the ARB in May, 1998.

3. DESCRIPTION OF MEASUREMENTS

The aircraft characteristics, its instrument configuration, and the various sampling systems aboard the aircraft are documented in the following sections. Also provided is a summary of the dates and times of sampling flights. The summary identifies the flight route flown and the number of grab samples collected during each flight. Maps are provided that show the typical sampling routes and a table is provided that identifies each sampling location.

3.1 AIRCRAFT

The STI Piper Aztec is shown in Figure 2-2. It is a model PA23-250 twin engine, low-wing aircraft with retractable landing gear. This aircraft was chosen as an air quality sampling platform because of its stable flight characteristics, available electrical power, load-carrying capabilities, and relatively low maintenance requirements. In addition, the Aztec can sample for periods of up to 4.5 hours. The aircraft has been operated on similar air quality sampling programs since 1985.

The aircraft's 190 amp, 28-volt DC electrical system provides power to two 1000 watt (115 volt AC, 60 Hz) inverters. The inverters (Avionic Instruments, Inc. Model 2A1000-1G), in turn, provide the power used by the standard commercial (115 volt AC, 60 Hz) air quality sampling equipment. Instruments or equipment requiring a DC power source are powered directly from the aircraft's 28-volt electrical system. All research equipment is protected by a separate circuit breaker installed in the aircraft's breaker panel as well as by standard built-in fuses and circuit breakers.

The aircraft is equipped with a radar transponder. This allowed FAA flight controllers to determine the position of the aircraft, and it also provided controllers with a direct readout of the aircraft's altitude (a feature called "Mode C"). These features were required by the FAA in order to coordinate sampling patterns flown by the research aircraft with other air traffic.

The aircraft was operated in "Restricted Category". This designation was necessary because of modifications made to the aircraft during installation of sampling equipment. The aircraft was inspected and certified for use in this category by the FAA. All necessary certifications were obtained prior to the ferry flight to the Camarillo airport where the aircraft was based throughout the study.

When an aircraft is operated in a restricted category, flight operations over populated areas and at airports providing commercial services are either limited or prohibited unless special operating permits (waivers) are obtained from the FAA. Due to program sampling requirements, waivers were required. The necessary waivers were obtained before the start of the sampling program.

Flight plans were reviewed with the appropriate FAA authorities, and all sampling was coordinated with the FAA.

3.2 INSTRUMENTATION

Table 3-1 lists the real-time continuous sampling equipment operated aboard the Aztec. The table lists the equipment model and manufacturer, the analysis technique, instrument ranges available for use, the approximate response time to 90 percent, and the approximate resolution of each instrument. Several instruments aboard the Aztec were not required by the contract. These instruments were operated and their data processed, although they were not rigorously calibrated. These instruments are also identified in the table. Data from these instruments were included in the aircraft database, but their data should be used with caution, knowing that rigorous calibrations and/or editing were not performed. All required measurements were processed, quality controlled, and reported as "Level 1" quality controlled data.

As shown in the table, grab samples to be analyzed for VOC and carbonyl concentrations were also collected aboard the aircraft. The collection media and sampling systems were provided by CE-CERT.

3.3 SAMPLING SYSTEMS

3.3.1 Access to Ambient Air

Figure 3-1 shows the air inlets and sensors on the outside left side of the aircraft. Access to ambient air for the instruments is provided by the three aluminum ("access") tubes installed one above the other in a replacement plate fit to the aircraft window (dummy window). The purpose of these tubes is to provide access to ambient air. However, they are not part of the sampling train (see below), and sampling air does not come in contact with the aluminum. The tubes are 4.5 cm (1-3/4 in) in diameter, extend about 15 cm (6 in) beyond the skin of the aircraft, and face forward into the airstream. The inlet to each access tube is near the 1/3 cord point of the wing (i.e., the front of the wing). Exhaust from the aircraft engines exit the engine nacelles under the wing near the trailing edge, well away from the sample inlets.

Figure 3-2 is a schematic drawing of the sample air access systems used for ozone, VOC, and carbonyl sampling. The drawing shows that the top two access tubes were used for cooling and ventilation of sampling equipment inside the aircraft. Sample air for ozone, carbonyl, and VOC sampling was obtained using Teflon tubes strung through the bottom access tube.

Table 3-1. Sampling instrumentation operated aboard the STI aircraft.

Parameter	Sampler Manufacturer and Model	Analysis Technique	Normal Measurement Ranges (Full Scale)	Time Response (to 90 Percent)	Approximate Lower Quantifiable Limit
NO/NO_y	Thermo Environmental Model 42S	Chemiluminescence	50,100,200, ppb	< 20 sec.	0.1 ppb
NO_1/NO_w[a]	Thermo Environmental Model 42S	Chemiluminescence	50,100,200, ppb	< 20 sec.	0.1 ppb
O_3	Monitor Labs 8410E	Chemiluminescence	200, 500 ppb	12 sec.	2 ppb
Dew Point	Cambridge Systems 137-C	Cooled Mirror	-50 to 50°C	0.5 sec./°C	0.5°C
Altitude	II-Morrow	Altitude Encoder	0 - 5000 m msl	1 sec.	1 m
Altitude (backup)	Validyne P24	Pressure/Transducer	0 - 5000 m msl	< 1 sec.	5 m
Temperature	YSI/MRI	Bead Thermister/ Vortex Housing	-30 to 50°C	5 sec.	0.3°C
Temperature (backup)	Rosemont 102 AV/AF	Platinum Resistance	-50 to +50°C	1 sec.	0.5°C
Turbulence[b]	MRI 1120	Pressure Fluctuations	0 - 10 $cm^{2/3}$ s^{-1}	3 sec.(60%)	0.1 $cm^{2/3}$ s^{-1}
Broad Band[b] Radiation	Epply	Pyranometer	0 - 1026 W m^{-2} Cosine Response	1 sec.	2 W m^{-2}
Ultraviolet[b] Radiation	Epply	Barrier-Layer Photocell	295 - 385 nm 0 - 34.5 W m^{-2} Cosine Response	1 sec.	0.1 W m^{-2}
Position	Garmin 250	GPS	Lat.-Long.	< 1 sec.	50 m
Data Logger (includes time)	STI 486 System	Zip Drive & Hard Disk Recording	± 9.99 VDC Disks & Hard Disk	Records data 1 s^{-1}	.005 VDC
Printer	Seiko DPU-411-040			Prints out data every 10 secs and at every event or data flag change.	
VOC/Carbonyl	Grab samples collected using CE-CERT supplied media and systems				
Aztec AC Power (2 units)	Avionic Instruments, Inc. Model #2A-1000-1A	Static Inverter	2000W 110V 60 Hz	-	-

a This instrument provided a duplicate NO measurement (labeled as NO_1) and measured NO_y with nitric acid and aerosol nitrate removed by a nylon inlet filter (called NO_w).

b These instruments were installed on the aircraft and operated, but they were not required by the contract and they were not rigorously calibrated. Data from these sensors have been edited but STI does not warrant the accuracy of the reported data.

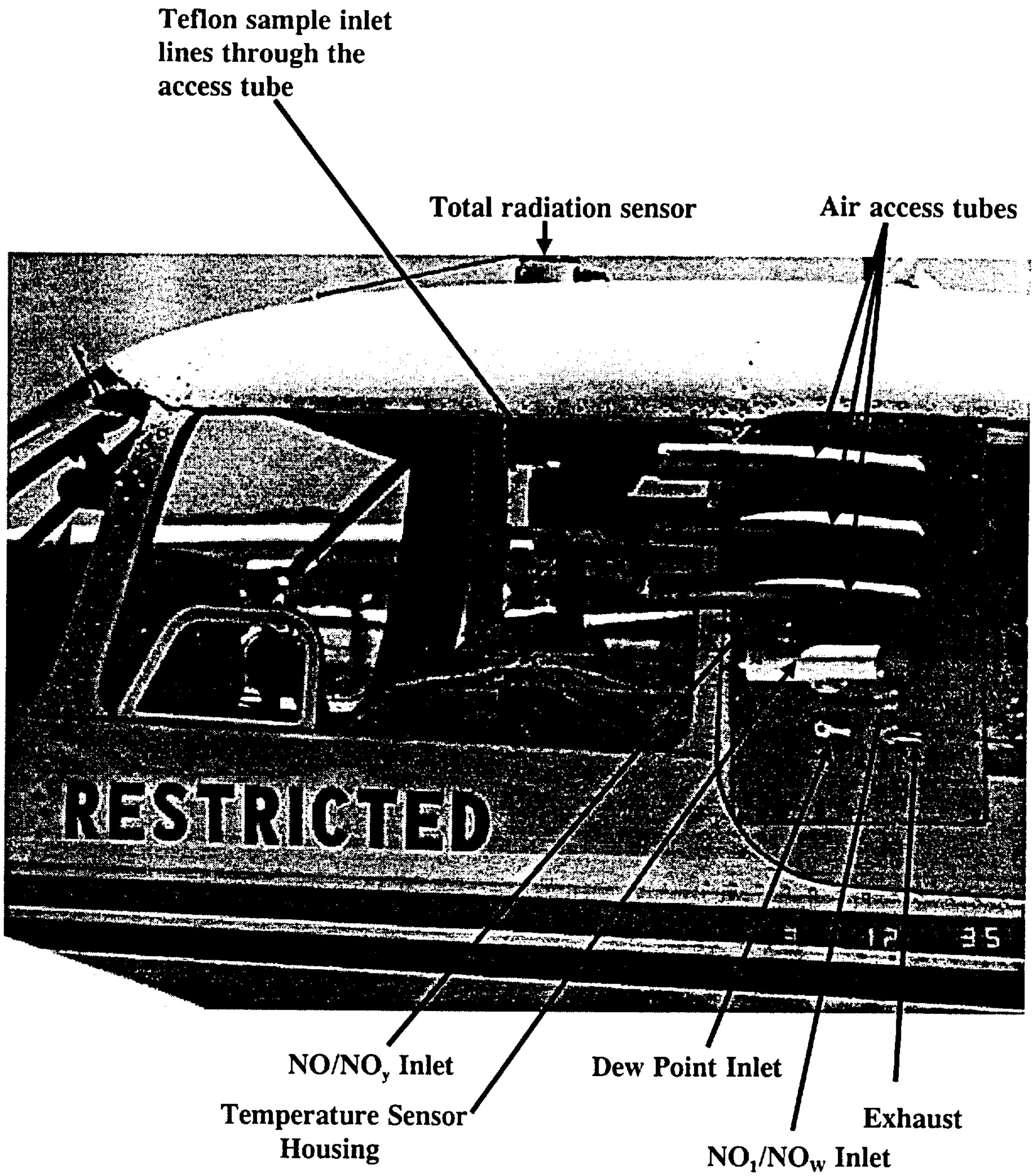

Figure 3-1. Sensor location and sample air inlet systems on the Aztec.

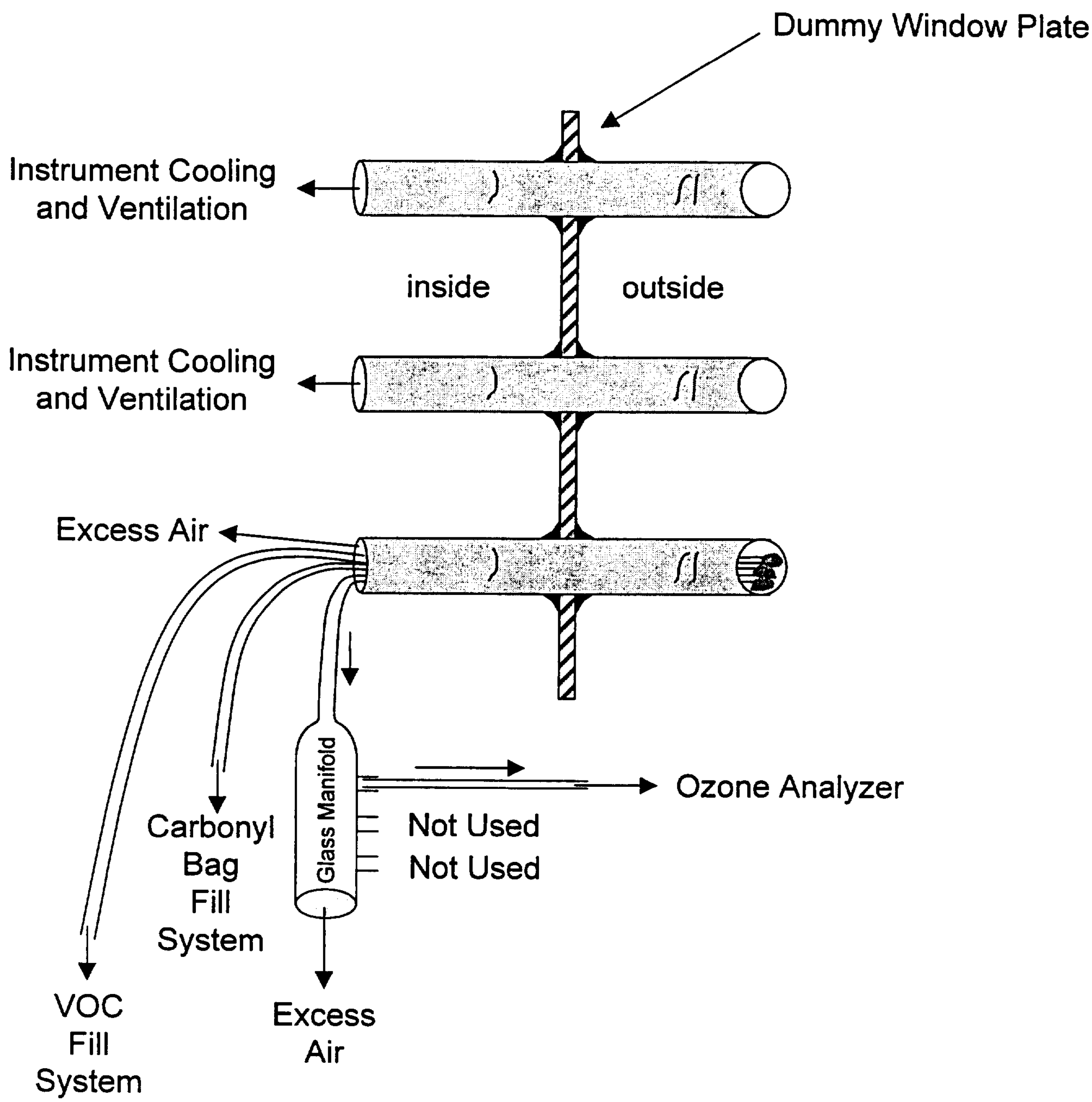

Figure 3-2. A schematic drawing of the sample delivery systems used for ozone, VOC, and carbonyl sampling (as viewed from the front looking back along the right side of the aircraft).

Two 9.5 mm (3/8 in) outer diameter (o.d.) and one 6.5 mm (1/4 in) o.d. Teflon sample inlet lines were inserted through the bottom access tube in the dummy window. These sample lines were used to deliver sample air used by the ozone analyzer, the VOC sampling system, and the carbonyl (bag) sampling system. The outside ends of the Teflon lines extended slightly beyond the forward edge of the access tube (Figure 3-1) and were thus exposed directly to ambient air. During flight, airflow through the Teflon lines and access tubes was provided by ram air pressure.

To address concerns about losses of oxides of nitrogen species in long sampling lines, and thus reduced sensitivity of the sampler to NO_y species, a special sample inlet system was designed, built, and installed on the Aztec. The outside portion (NO/NO_y inlet) can be seen in Figure 3-1. An engineering design drawing of the NO_y inlet system is shown in **Figure 3-3** with a schematic drawing of the NO/NO_y (Inlet #1) and NO_1/NO_w (Inlet #2) systems shown in **Figure 3-4**.

The objective of the NO_y inlet design is to prevent absorption of highly reactive species by the wall of the sampling inlet tube by reducing the length of the sampling line from the sample inlet to the NO_y converter. This was accomplished by utilizing a modified NO/NO_y analyzer (TECO 42S after modification) with a removable NO_y converter. The converter was mounted on the inside of the window plate to bring it as near as possible to the sample inlet. Sample air was provided to the converter by means of a Teflon-coated stainless steel inlet tube, a short stainless steel Teflon-coated manifold, and a short stainless steel sample tube to the converter itself.

Calculations for wall adsorption of NO_y species were not performed, as no theoretical or empirical equations for wall adhesion in turbulent flow were readily available. Regardless, residence times from the free air-stream inlet to the converter were computed based on dimensions and flow velocities. The residence time of the sample in the 8.77 mm (0.344 in) inner diameter (i.d.) inlet tube from the outside of the aircraft to the start of the converter inlet tube (points 1 to 2 in Figure 3-3) was computed to be approximately 15 msec. The residence time of the sample from the inlet of the converter tube to the actual converter (points 2 to 4 in Figure 3-3) was computed to be 180 msec. This rate was determined by the fixed sample flow rate through the converter of 1 liter per minute (lpm). Thus, the total residence time of the sample in the inlet system was approximately 200 msec. In addition to this short residence time, the portion of the inlet from point 2 to point 4 was stainless steel heated by excess heat generated in the converter core and conducted throughout the length of the inlet tube. Temperatures along the converter inlet tube inside the aircraft were approximately 45-60°C. The converter itself was operated at 350°C. Note the placement of the Teflon particle filter for the NO_y sample down-stream of the converter.

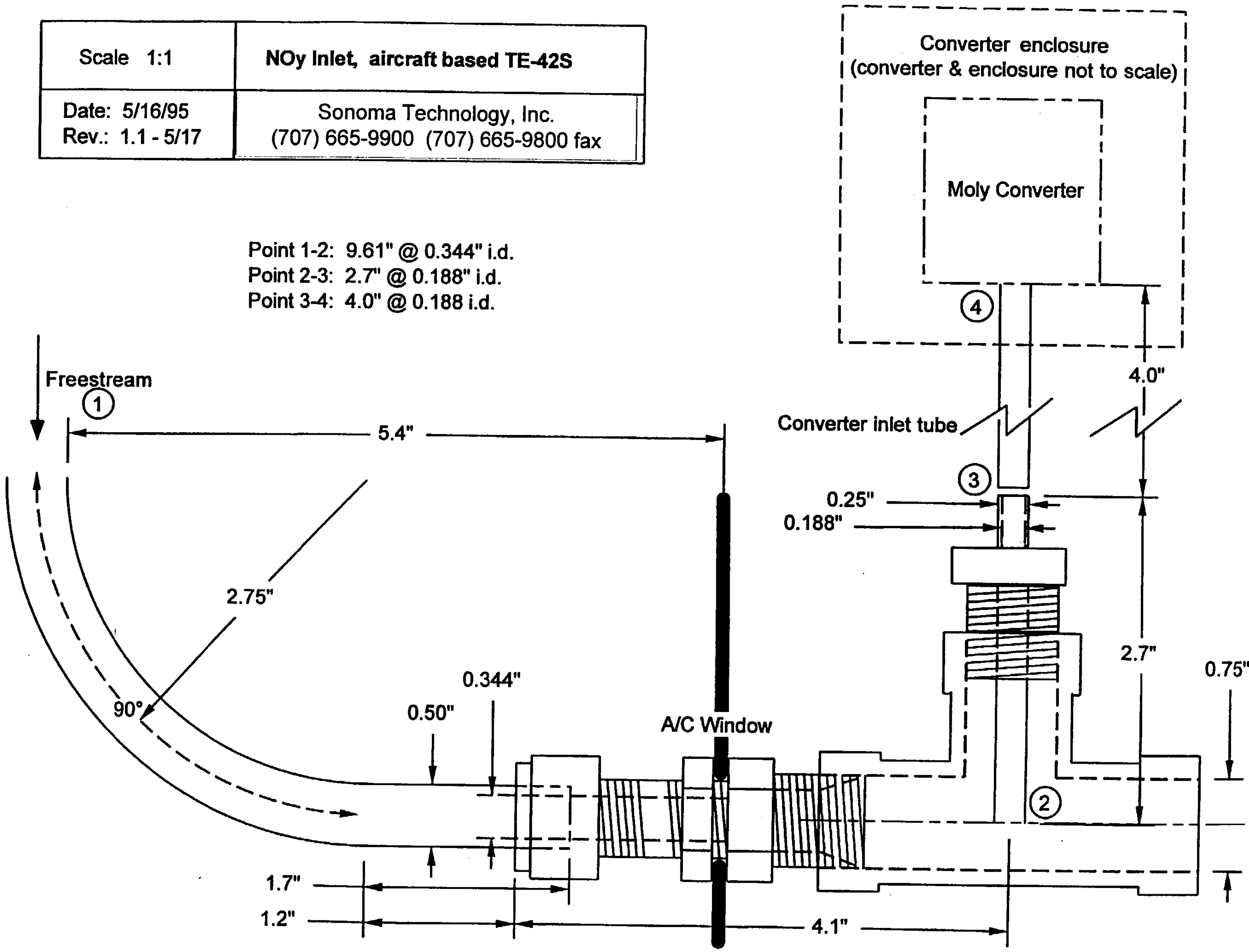

Figure 3-3. An engineering design drawing of the NO_y inlet system used on the STI Aztec.

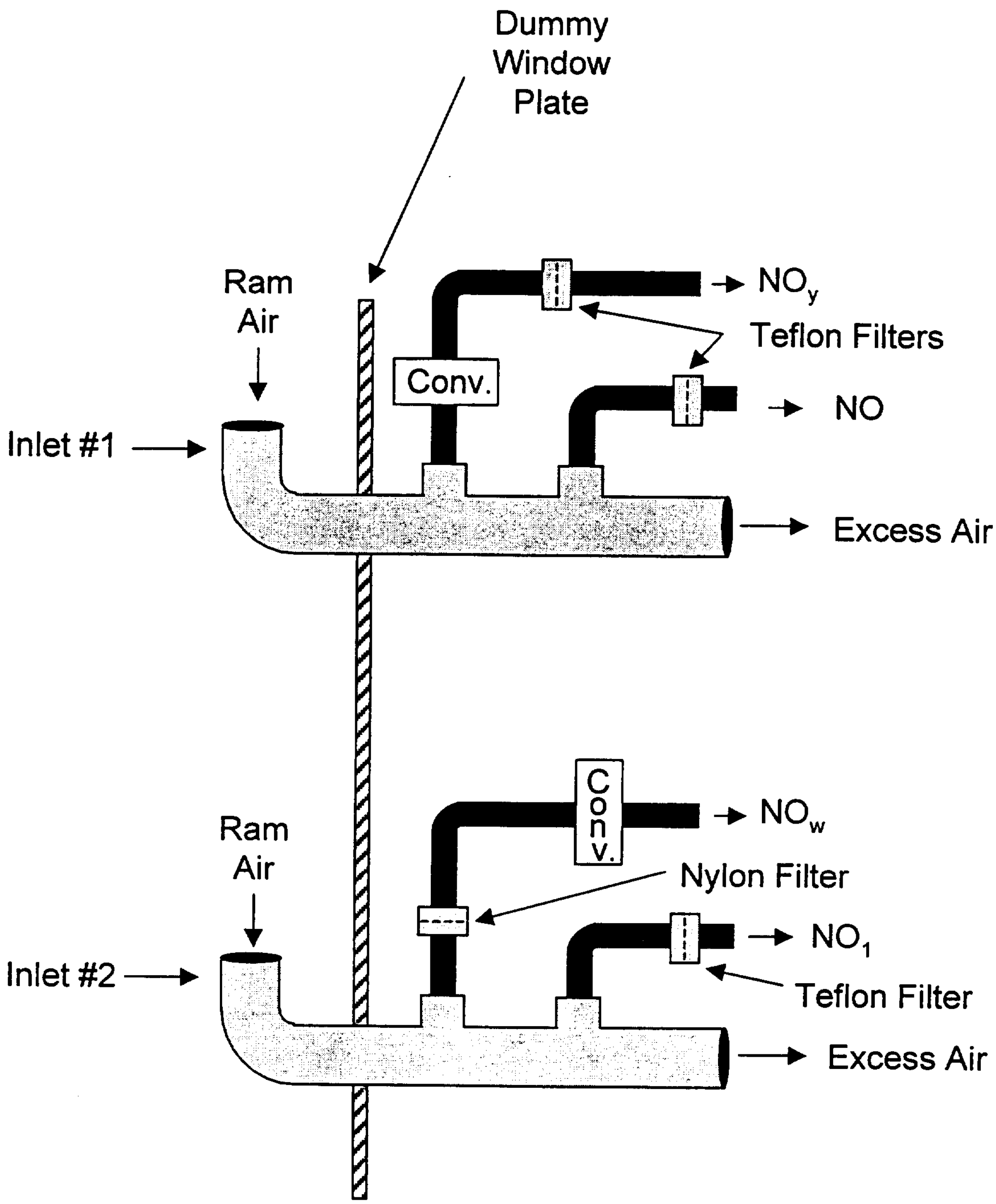

Figure 3-4. A schematic drawing of the inlet systems for the NO_y and NO_w instruments. Note the different placement of the filter with respect to the converter for the NO_y and NO_w instruments.

As previously mentioned, two NO/NO_y monitors were operated aboard the aircraft. The instruments were identical TECO 42S models operated in a similar manner. The second monitor provided a duplicate NO measurement (labeled as NO_1) and measured NO_y with nitric acid and aerosol nitrate removed by a nylon inlet filter (labeled as NO_w). The placement of the nylon filter was up-stream of the converter, as shown in Figure 3-4. Thus, nitric acid and aerosol nitrate were removed from the sample air before it reached the converter. During data processing, the difference between NO_y and NO_w was calculated giving a measure of the nitric acid and aerosol nitrate in the air that was being sampled. This difference was labeled HNO_3 on data plots.

The inlet tubes for the NO_y and NO_w systems were removable. After each day's flight, the tubes were removed and cleaned before further sampling was performed.

3.3.2 Sample Delivery Systems

__Real-time continuous sensors__

One of the 9.5-mm inlet lines (discussed in Section 3.3.1) was used to provide sample air to a glass manifold from which the ozone monitor sampled. The manifold consisted of a 9.5-mm inlet into a glass expansion chamber (Figure 3-2) measuring 23 cm (9 in) in length by 2.5 cm (1 in) in diameter. Three 6.5-mm static sample ports were attached to the side of the expansion chamber. Volume expansion inside the chamber slowed the incoming sample airflow. A Teflon sampling line from the ozone monitor was connected to the first port (nearest the manifold inlet). The other two ports were not used. Excess air from the glass manifold was vented into the cabin of the aircraft. The ozone monitor was operated using a Teflon particle inlet filter.

Four Teflon sample lines (two for the NO/NO_y instrument and two for the NO_1/NO_w instrument) delivered sample air from the inlet systems directly to the analyzers. The sample lines were cut to the same length in an attempt to match (time-wise) recorded concentration values.

All connections used Teflon fittings. Thus, for the gas analyzers, an incoming air sample was only in contact with Teflon, stainless steel, or glass from the atmosphere to the inlet of a sampling instrument.

__VOC grab sampling__

The VOC sampling system shown schematically in Figure 3-2 and **Figure 3-5** was provided by CE-CERT and consisted of:

- A 2.4-m (8 ft) length of 6.5-mm-diameter Teflon sample inlet tube,
- Two KNF Neuberger pumps (DC voltage) operated in parallel,
- A Veriflo flow regulator with a preset 25 psi back pressure,
- A 1.8-m (6 ft) length of 6.5-mm Teflon sample delivery tubing,
- A two-way toggle valve and pressure gauge assembly (called a "purge tee"), and
- 3.0 liter stainless steel canisters.

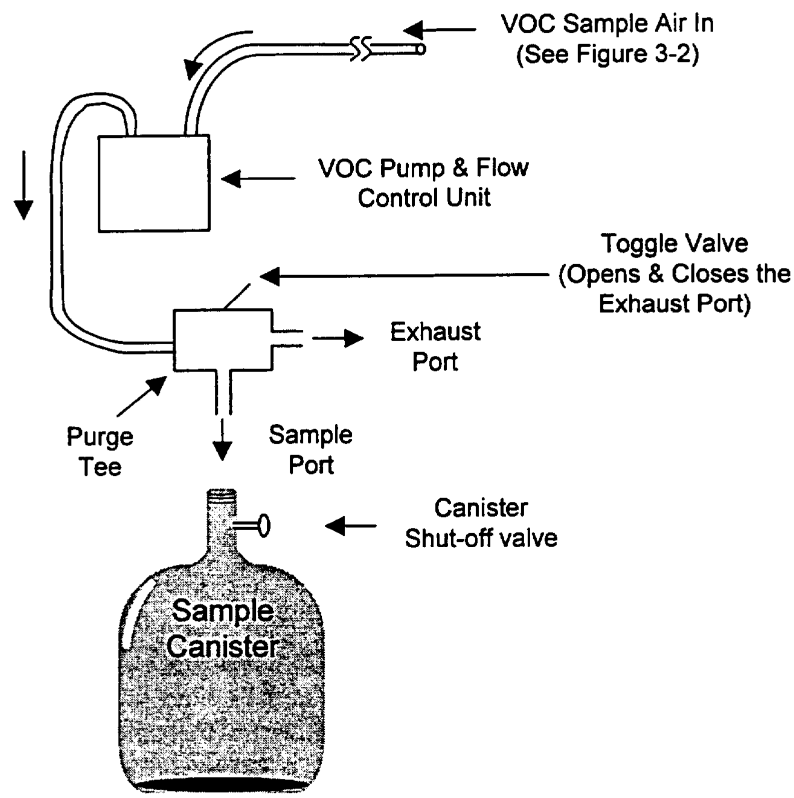

Figure 3-5. A schematic drawing of the VOC sampling system.

The canisters were Stabilizer 3.0 liter canisters manufactured by Meriter using 316L low-carbon grade stainless steel. The canister valve assembly was a Bellows Seal Valve with a Testel® Seat. Each canister was evacuated, baked, sealed, and labeled before being delivered to the aircraft operations base in Camarillo. After sampling, the VOC canisters were returned to CE-CERT for analysis.

Teflon tubing was cleaned and preconditioned prior to installation in the aircraft. Internal pump components that came in contact with sample air were all Teflon coated. Components of the purge tee that came in contact with sample air were stainless steel. Connections between canisters and the sample line were made using ParkA-lok 1/4 in Swage type stainless steel fittings.

As described in Section 3.3.1 and shown in Figure 3-2, the 6.5-mm o.d.Teflon sample inlet tube was inserted through the bottom access tube in the sampling window. The other end was connected to the VOC pumps. The pumps supplied air through the flow regulator and sample delivery tubing to the purge tee. The position of the toggle valve on the purge tee allowed sample air to either be exhausted into the aircraft cabin or directed into the sample canister.

The flow regulator was adjusted to fully pressurize a canister in about two minutes. Since bag and VOC samples were collected together, this fill rate was selected to match the fill time for bag samples (discussed below).

During flight, the pumps were run continuously to purge the sampling system. Whenever the aircraft was on the ground, the VOC system was sealed on both ends to avoid contamination.

<u>Carbonyl grab sampling</u>

The system for collection of grab bag samples is shown schematically in Figure 3-2 and **Figure 3-6**. The system was provided by CE-CERT and consisted of a 1.2-m (4-ft) length of 9.5-mm o.d. Teflon tubing that was inserted through the bottom access tube on the sampling window. The inlet tubing terminated in a two-piece reduction assembly consisting of 9.5-mm o.d. tubing and 6.4-mm o.d. tubing telescoped together.

The sample bags (40-liter volume) were constructed of 2-mil Tedlar material. The inlet on each bag was a "Push to Open - Pull to Close" type stainless steel valve. The bag valve was connected to the sample line by a snug friction fit between the valve and the tubing. The bag was filled using ram air pressure. When not sampling, air flow through the inlet tubing provided a continual purge of the system.

After an air sample was collected aboard the aircraft and the sample bag had been disconnected from the sampling system, the sample bag was placed inside a larger dark opaque plastic ("trash") bag. These bags were used to inhibit photochemical reactions in the sample bags until the contents could be further stabilized during ground operations performed by CE-CERT.

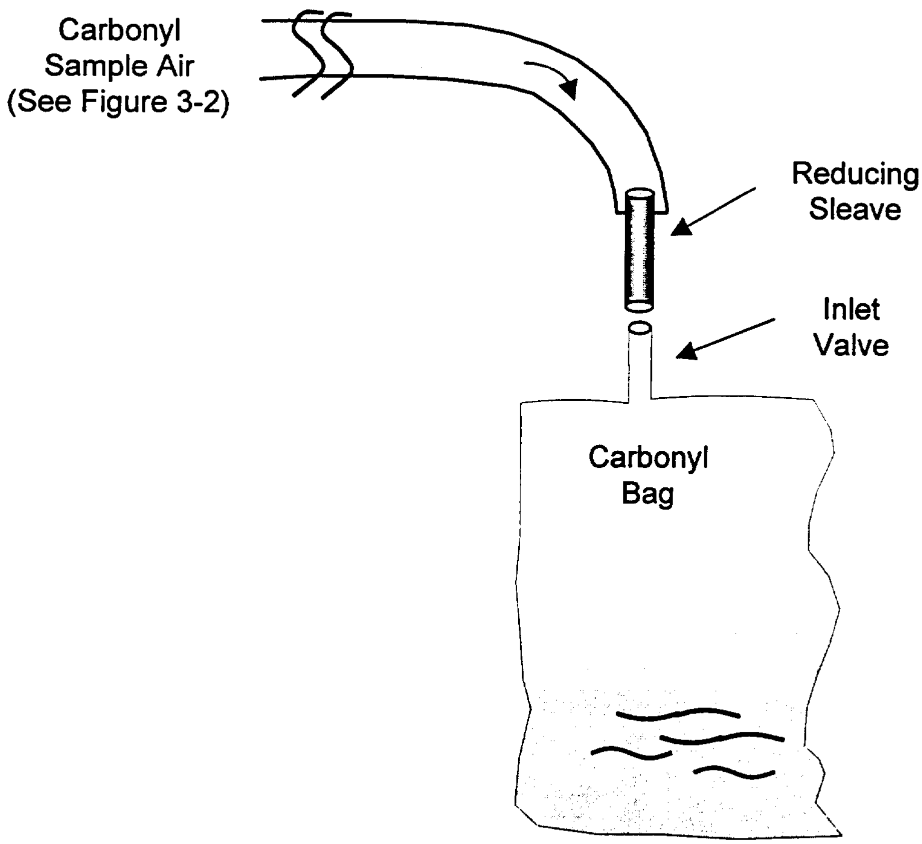

Figure 3-6. A schematic drawing of the carbonyl bag sampling system.

Within 15 minutes after landing, bag samples that had been collected during the just completed flight were transferred from the aircraft to CE-CERT personnel. For flights ending at the Riverside airport, the CE-CERT representative transported these samples directly to the nearby CE-CERT laboratory for further processing. At Camarillo, CE-CERT transferred the contents of each bag through a dinitrophenylhydrazine (DNPH)-impregnated cartridge (one cartridge per bag). Typically, these sample transfers were completed within about an hour of receiving the bag samples. The DNPH cartridges were stored in a cooler except during sample transfer. After sample transfers were completed, the CE-CERT representative returned the DNPN cartridges to CE-CERT.

Sample bags were reused after ground-based transfer operations had been completed. Conditioning of bags prior to use (or reuse) was performed by CE-CERT personnel.

3.4 SENSOR MOUNTING LOCATIONS

The sensors aboard the aircraft can be divided into two groups: external- and internal-mounted sensors.

3.4.1 External-mounted Sensors

The primary temperature probe used aboard the Aztec is mounted on the outside of the sampling window plate. The vortex housing assembly that contains the bead thermistor sensor is shown in Figure 3-1. Holes drilled through the sampling window provide electrical access to the sensor. A secondary (back-up) temperature probe is mounted under the right wing of the aircraft.

Dew point, turbulence, ultraviolet radiation, and total radiation were also measured. The inlet system for the dew point sensor is mounted on the outside of the sampling window (Figure 3-1), and the sensor head itself is mounted on the inside of the window. The turbulence sensor is mounted under the left wing.

Ultraviolet and total radiation sensors are mounted on the top of the aircraft cabin. Because of their placement, data from these two sensors are subjected to antenna wire shadows, varying aircraft attitudes, and radio transmission interference. Though not part of the required data set, these sensors were operated but they were not rigorously calibrated. Their data were edited but STI does not warrant the accuracy of the reported data.

3.4.2 Internal-mounted Sensors

The continuous real-time air quality sensors, data acquisition system (DAS), printer, and associated support equipment were mounted in instrument racks installed on the left side of the aircraft cabin, behind the pilot.

Primary altitude data were obtained from an encoding altimeter mounted under the aircraft's instrument panel. A secondary (back-up) measurement of altitude was provided by a Validyne pressure transducer mounted in the rear left of the aircraft cabin. Both were connected to outside static air points.

Position data were obtained from a Garmin Model 250 GPS receiver mounted in the aircraft's instrument panel. The digital output from this unit was fed into the on-board data acquisition system.

3.5 INSTRUMENT EXHAUST SYSTEM

Although the exhaust system of typical air quality instruments contain some provisions for scrubbing exhaust gases, airborne safety and the integrity of the sampling being performed requires additional safeguards. For example, the ozone monitor used aboard the aircraft required a steady supply of ethylene (C_2H_4). It is possible that some excess ethylene could remain in the instrument's exhaust, which could interfere with VOC measurements if the exhaust is not properly vented. To avoid potential problems, the exhaust streams from all analyzers are combined using an exhaust manifold that vents outside the aircraft. The exhaust tube (external portion of the system) can be see in Figure 3-1. Instrument exhaust gases are pumped out of the cabin and exhaust well aft of sensor inlet systems. In-flight airflow past the exhaust tube, also carries these gases away from the inlet systems.

3.6 SUMMARY OF FLIGHTS, TIMES, AND ROUTES

The SCOS97 management team selected the sampling days and routes to be flown. Typically the Aztec flew two flights on each selected day.

During the sampling program, the aircraft flew 29 flights: 24 regular sampling missions along the northern boundary of the study area, one "special" flight to examine transport to Ventura County and Santa Barbara, two over-ocean flights when the primary SCOS97-NARSTO aircraft for this route was not available, and separate inter-comparison flights with both the UCD and U.S. Navy sampling aircraft.

Table 3-2 summarizes the date, sampling period, flight route, and number of VOC and carbonyl samples collected during each SCOS97 flight. Each flight was assigned an identifying number (or name for the inter-comparison flights) that is also shown in the table. Details of each flight are presented in the three-volume data report that was delivered to the ARB. **Please note that all sampling was performed using a Pacific Standard Time (PST) basis and all STI data are reported using that standard.**

Table 3-2. Summary of STI sampling flights during SCOS97.

Flight Number	Date/Sampling Period (PST)	Flight Route	Number of VOC/Carbonyl Samples Collected
1	7/14/97 11:30-14:58	Western Boundary	5/5
2	8/04/97 04:37-08:17	Northern Boundary	5/5
3	8/04/97 14:04-16:11	Basin	1/1
4	8/05/97 04:32-07:12	Basin	3/3
5	8/05/97 13:09-16:55	Northern Boundary	3/3
6	8/06/97 04:38-07:36	Basin	2/2
7	8/06/97 12:58-16:48	Northern Boundary	3/3
8	8/07/97 08:21-10:46	Special	3/3
9	8/22/97 04:46-08:16	Northern Boundary	5/5
10	8/22/97 14:07-16:10	Basin	1/1
11	8/23/97 04:30-07:14	Basin	3/3
12	8/23/97 13:08-16:53	Northern Boundary	3/3
13	9/03/97 11:08-14:59	Western Boundary	6/6
14	9/04/97 04:58-08:44	Northern Boundary	5/5
15	9/04/97 14:08-16:30	Basin	1/1
16	9/05/97 04:59-08:53	Northern Boundary	3/5
17	9/05/97 13:58-16:19	Basin	0/1
18	9/06/97 04:45-07:14	Basin	2/2
19	9/06/97 12:57-16:52	Northern Boundary	1/1
20	9/28/97 08:50-10:35	Basin	2/2
21	9/28/97 13:07-15:43	Basin	3/3
22	9/29/97 04:44-07:28	Basin	3/3
23	9/29/97 12:57-15:35	Basin	3/3
24	10/03/97 04:43-08:30	Northern Boundary	5/5
25	10/03/97 13:57-16:09	Basin	1/1
26	10/04/97 04:34-07:28	Basin	3/3
27	10/04/97 14:01-16:15	Basin	3/3
UCD	7/08/97 13:02-13:51	Inter-comparison	0/0
Navy	9/30/97 12:55-13:49	Inter-comparison	0/0

For the first day of a typical IOP, the aircraft would sample from Camarillo to Riverside during the morning flight using a Northern Boundary route that characterized conditions in the Mojave Desert. The afternoon flight would return to Camarillo using a Basin route that characterized conditions in the northern portion of the Basin. For the second and following days of an IOP, the aircraft would sample to Riverside using a Basin route during the morning flight and return to Camarillo using a Northern Boundary route in the afternoon. Sampling along each route consisted of a series of spirals, the aircraft climbing and/or descending (dolphin) between spiral locations, and constant level traverses flown along selected portions of the flight route. Data were collected continuously throughout each flight.

During the first day of an IOP, the intent was for the aircraft to characterize the boundary conditions in the northern and eastern regions of the study domain, including the Mojave Desert. **Figure 3-7** shows the Northern Boundary flight route used by the aircraft for the morning flight. Along the route, spirals were flown at the Camarillo airport (CMA), the Van Nuys airport (VNY), the Agua Dulce airport (L70), the Rosamond airport (L00), the Hesperia Radar Profiler Site (HES), the Yucca Valley airport (L22), the Banning airport (BNG), the Rialto airport (L76), and the Riverside airport (RAL). Spirals were typically made between the surface and 1000 to 1500 m above ground. Also, two constant level traverses were part of the flight plan - the first was flown from Rosamond to the Hesperia Profiler site and the second from R1 to Soggy Lake (SL).

The Basin flight route for the afternoon flight of the first day of an IOP is shown in **Figure 3-8**. For this flight, sampling was expected to begin at about 1400 PST. Spirals were flown at the Riverside, Rialto, Ontario (ONT), El Monte (EMT), Van Nuys, and Camarillo airports. An additional spiral was performed in Simi Valley (SIM), but could not be flown to the surface.

During IOP periods, the UCD aircraft sampled within the basin. It was based at the El Monte airport and performed spirals at the El Monte airport as part of each flight. Having the Aztec also sample at the El Monte airport provided additional inter-comparison data for the two aircraft and will be useful in studying temporal changes at this location.

For the second and following days of an IOP, the Aztec flew a Basin morning flight route shown in **Figure 3-9**. Spirals were flown at the Camarillo, Van Nuys, El Monte, Ontario, Rialto, and Riverside airports. Additional spirals were flown off-shore of Malibu (MAL), over Azusa (AZU), and above the San Gabriel reservoir (SGR).

Afternoon flights for the second and following days of an IOP followed the Northern Boundary route shown in **Figure 3-10**. These afternoon flights were scheduled to take off at about 1300 PST. During these flights spirals were flown at the Riverside, Rialto, Banning, Yucca Valley, Bohunk's (OCL6), Van Nuys, and Camarillo airports. One additional spiral was performed at the Hesperia Radar profiler site. Constant level traverse legs were flown from Yucca Valley airport to Soggy Lake, from Soggy Lake to the R1 reference point, from the Profiler site to the R2 reference point, and from R2 to the R3 reference point.

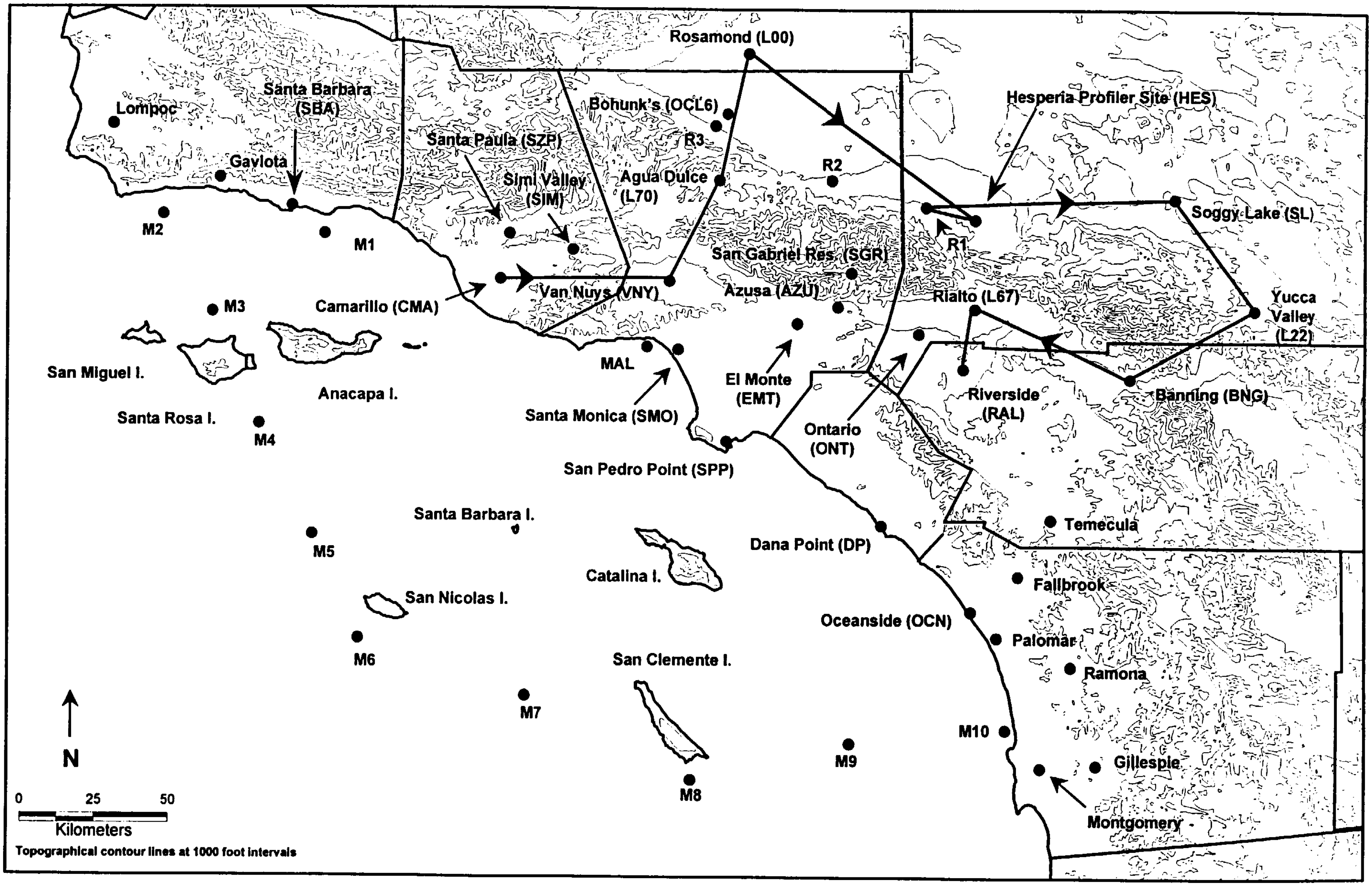

Figure 3-7. The Northern Boundary flight route flown the morning of the first day of an IOP.

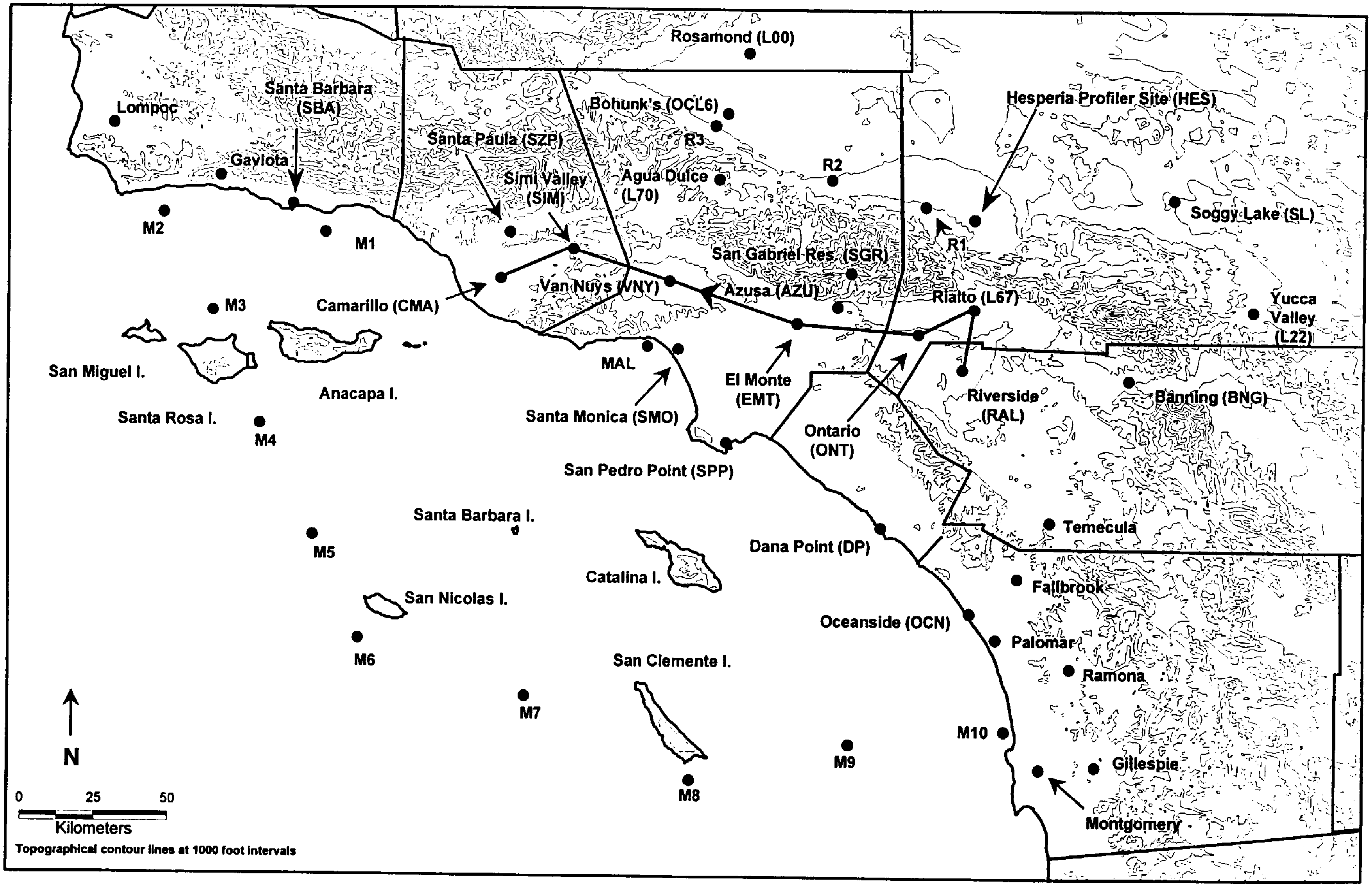

Figure 3-8. The Basin flight route flown during the afternoon flight of the first day of an IOP.

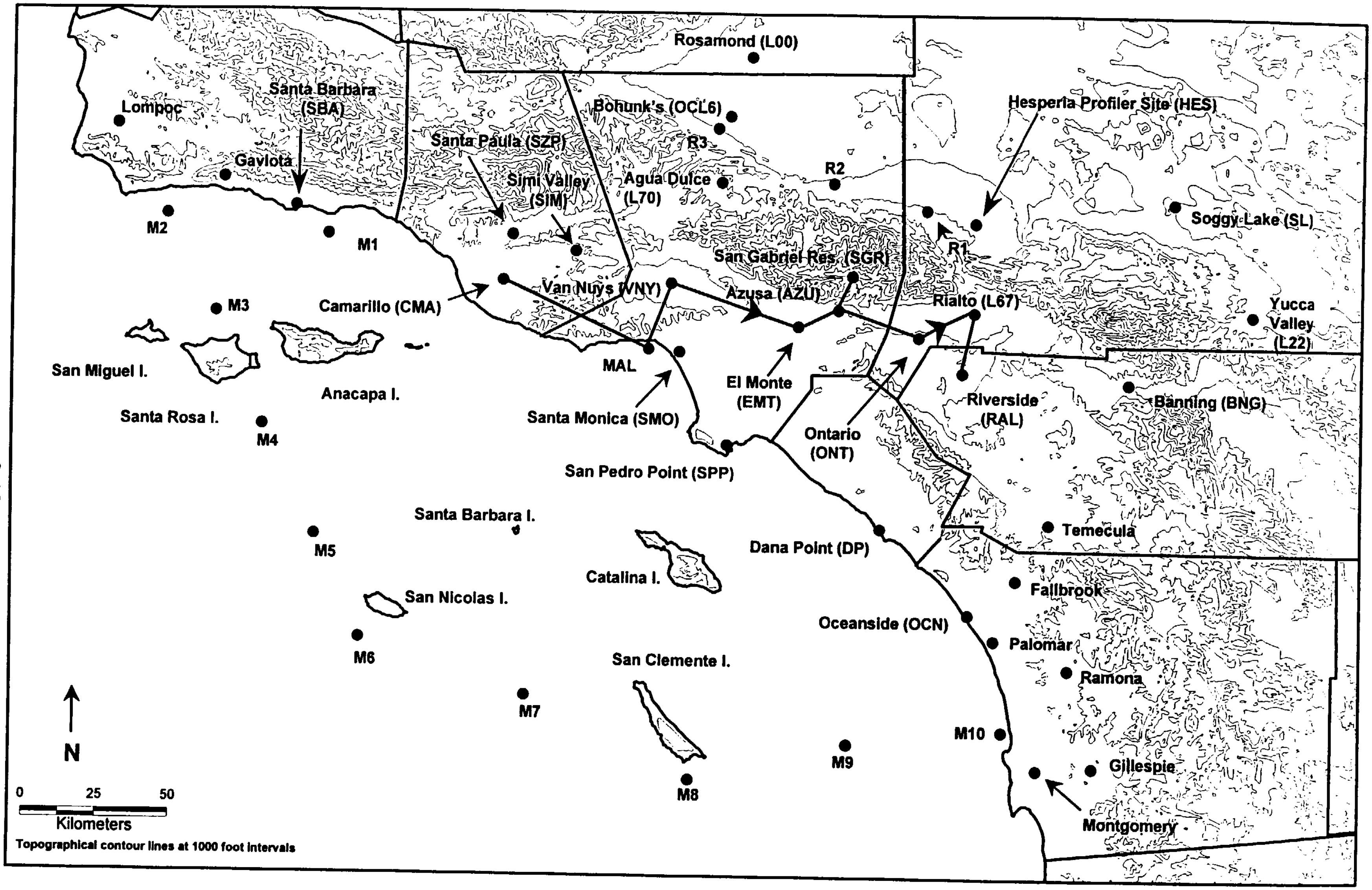

Figure 3-9. The Basin flight route for morning flights on the second and following days of an IOP.

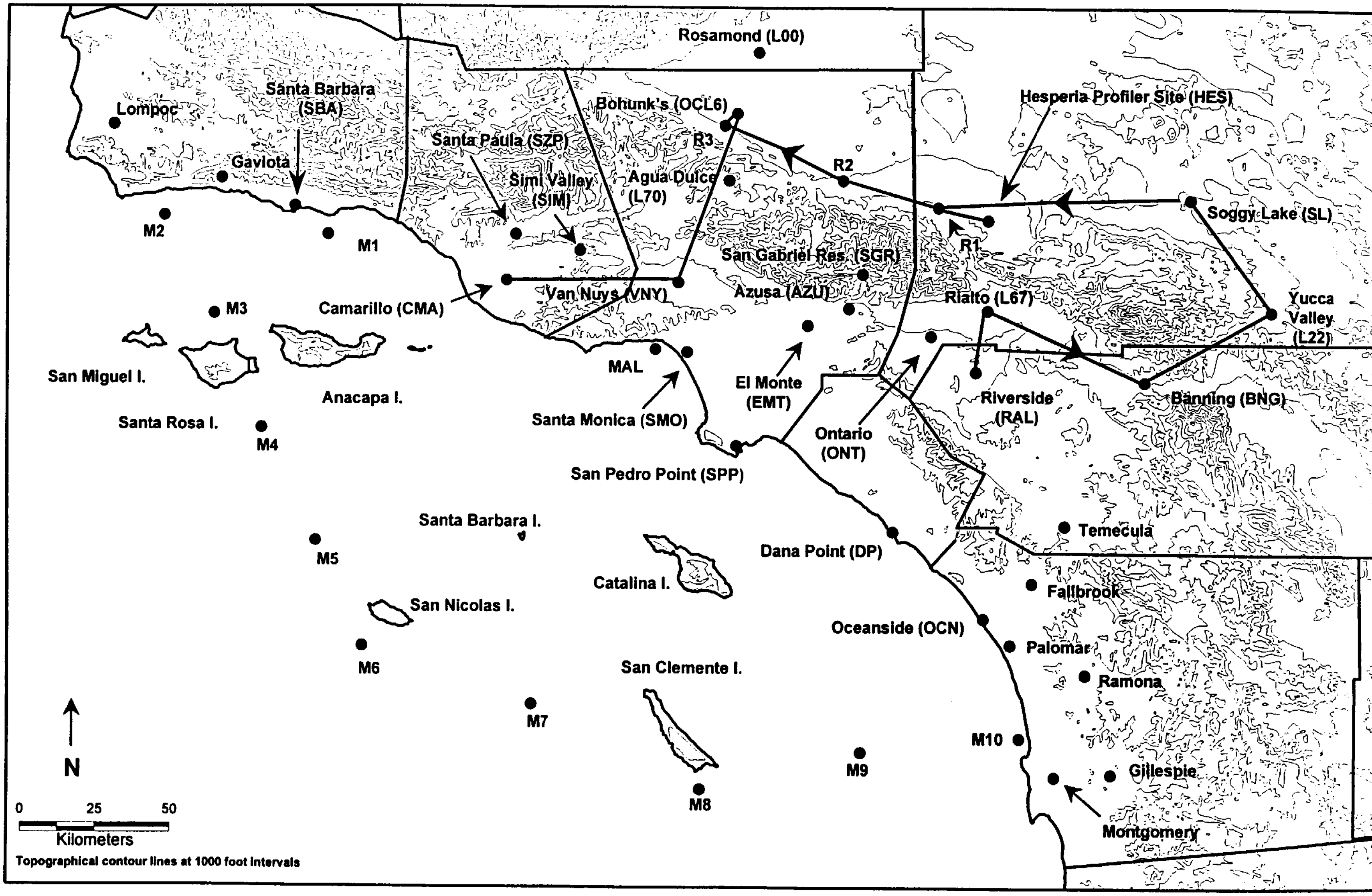

Figure 3-10. The Northern Boundary flight route for afternoon flights for the second and following days of an IOP.

Twice the STI aircraft was called on to provide back-up flights for the aircraft scheduled to perform over-ocean sampling. **Figure 3-11** shows the route that was flown on these flights. The aircraft departed from Camarillo and flew counterclockwise along the route. Sampling during these flights was performed as the aircraft was climbing or descending from one location to the next. A constant level traverse was flown from San Pedro Point (SPP) to Santa Monica (SMO). One spiral was flown at a location between Santa Monica and Malibu, and another spiral was flown at the end of the flight as the aircraft descended for landing at Camarillo.

On August 6, 1997, Mr. Bart Croes of the SCOS97 program management team contacted STI and requested a "special" flight for the next day. The purpose of this flight was to examine transport to Ventura County and Santa Barbara. A flight plan was developed by STI and approved by SCOS97 management. The sampling route that was used for the August 7, 1997 special flight is shown in **Figure 3-12**. Spirals were flown at the Camarillo airport, the Malibu offshore site, the Van Nuys airport, Simi Valley, the Santa Paula airport (SZP), the Santa Barbara airport (SBA), and again at the Camarillo airport as the aircraft descended for landing.

Sampling during the inter-comparison flight with the UCD aircraft consisted of a traverse from Azusa to the Cable airport, a spiral at Cable, a traverse back to the El Monte airport, and then a downward spiral and upward spiral at El Monte. During the inter-comparison flight with the Navy aircraft, an upward and downward spiral was flown at the Camarillo airport, and two constant altitude traverses were made from Camarillo toward Santa Barbara and back.

Table 3-3 shows the names, abbreviations, and locations of each sampling site. The table presents the site description (name), the two, three, or four character identifier assigned to the site, the ground elevation, and the latitude and longitude for each site. The identifiers are included in the magnetic media files and are useful for sorting purposes. A few locations shown in various figures (e.g., Lompoc, Gaviota, Temecula, Fallbrook, Palomar, Ramona, and Gillespie) were not used by the STI aircraft during sampling and, therefore, are not included in the table.

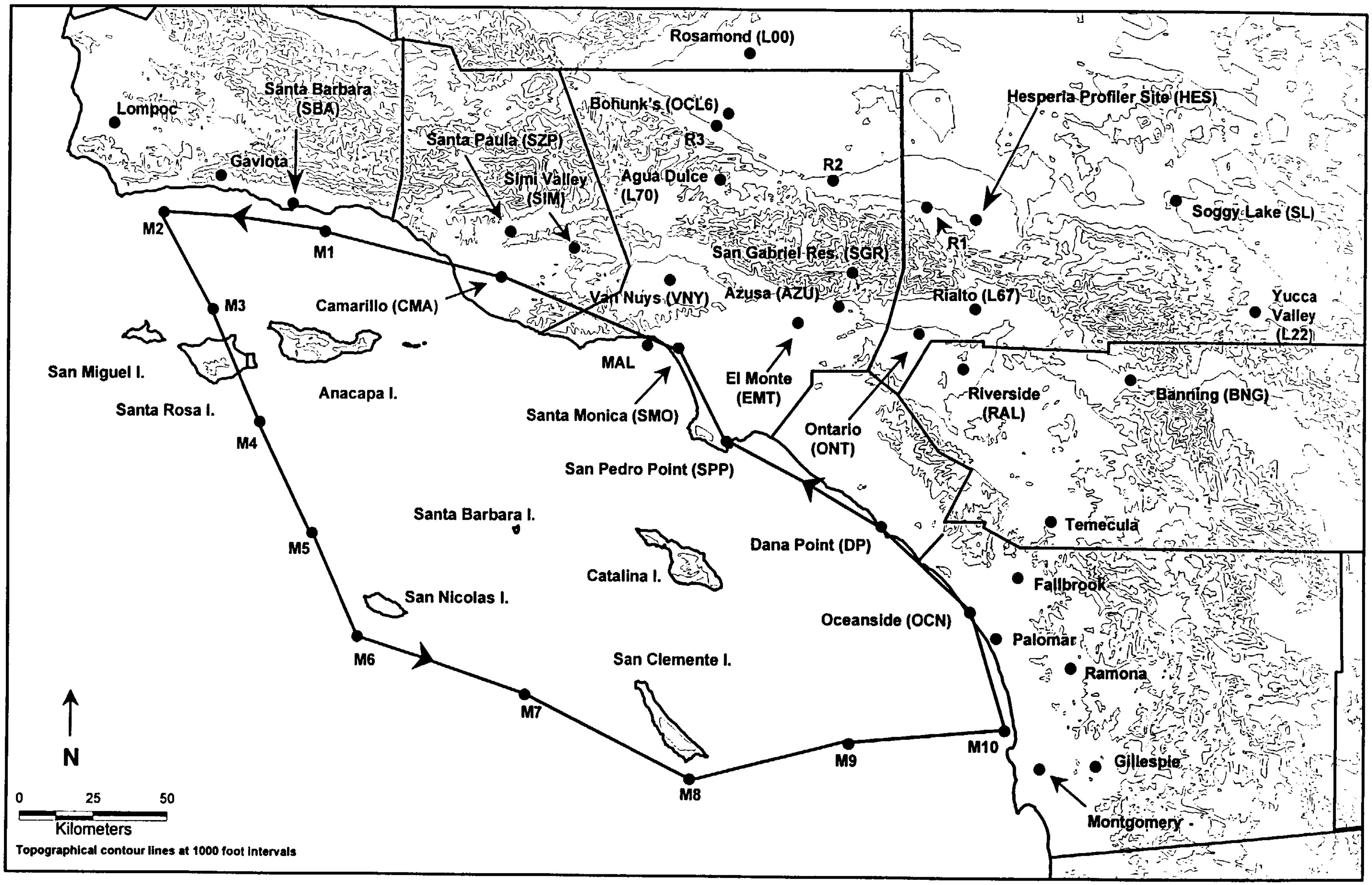

Figure 3-11. The Western Boundary flight route flown by the STI aircraft.

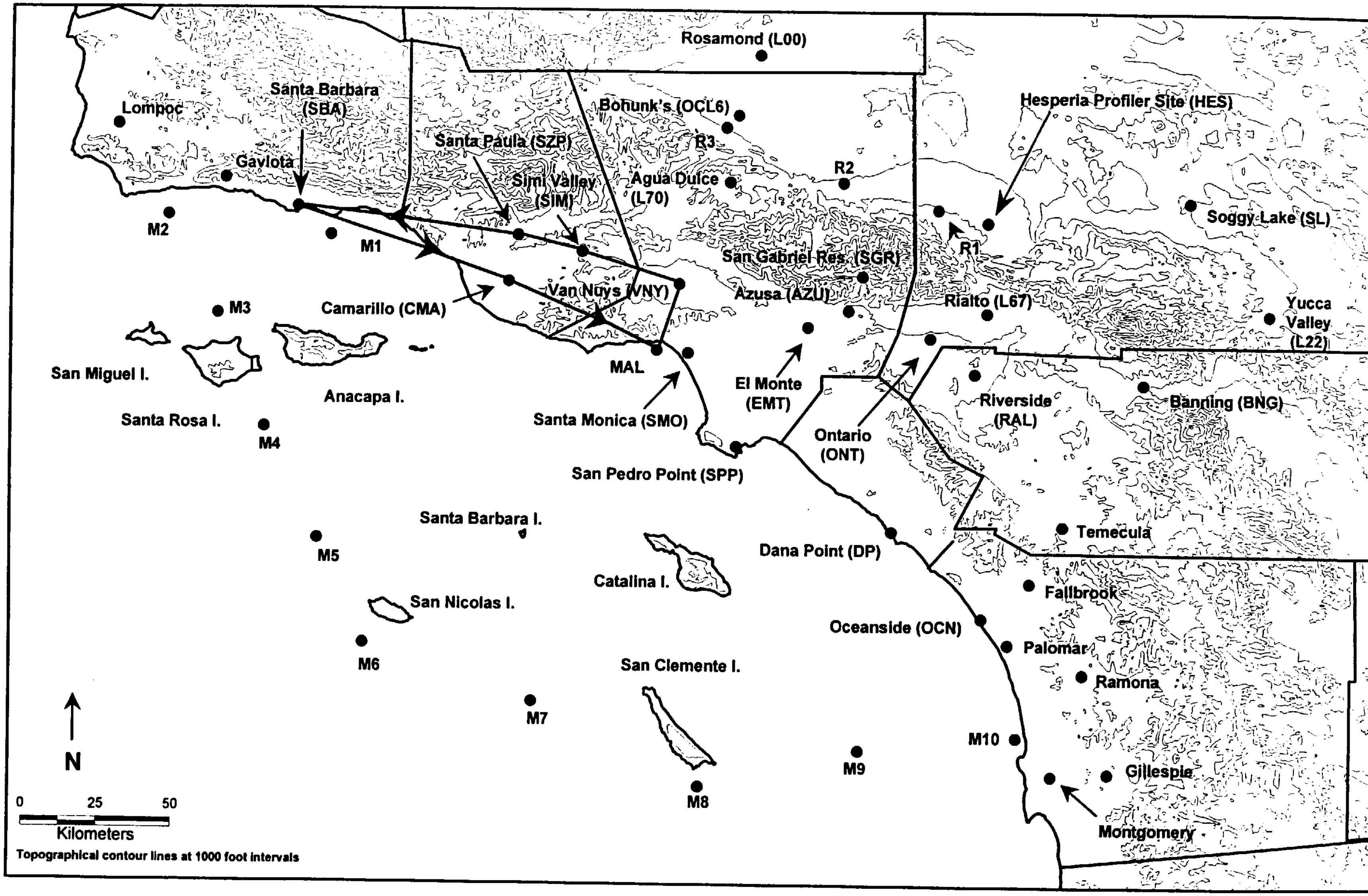

Figure 3-12. The flight route flown for the "special" sampling requested by SCOS97 management.

Table 3-3. Sampling locations used by the STI aircraft during the SCOS97 sampling program.

Site	ID	Elevation ft-msl/m-msl		Latitude	Longitude
Azusa	AZU	800	244	34° 08.0'	117° 53.3'
Banning Airport	BNG	2219	676	33° 55.4'	116° 51.0'
Camarillo Airport	CMA	75	23	34° 12.8'	119° 05.6'
Dana Point	DP	0	0	33° 29.4'	117° 44.1'
El Monte Airport	EMT	296	90	34° 05.1'	118° 02.0'
Hesperia Profiler site	HES	3198	975	34° 23.4'	117° 24.0'
Rosamond Airport	L00	2415	736	34° 52.2'	118° 12.5'
Yucca Valley Airport	L22	3224	983	34° 07.6'	116° 24.4'
Rialto Airport	L67	1455	443	34° 07.7'	117° 24.1'
Agua Dulce Airport	L70	2660	811	34° 30.2'	118° 18.7'
Overwater location	M1	0	0	34° 20.7'	119° 43.4'
Overwater location	M10	0	0	32° 53.9'	117° 17.5'
Overwater location	M2	0	0	34° 24.0'	120° 18.2'
Overwater location	M3	0	0	34° 07.0'	120° 07.5'
Overwater location	M4	0	0	33° 47.2'	119° 57.3'
Overwater location	M5	0	0	33° 27.7'	119° 45.9'
Overwater location	M6	0	0	33° 09.5'	119° 36.0'
Overwater location	M7	0	0	32° 59.6'	119° 00.2'
Overwater location	M8	0	0	32° 45.1'	118° 24.6'
Overwater location	M9	0	0	32° 51.5'	117° 50.8'
Offshore Malibu	MAL	0	0	34° 01.0'	118° 34.0'
Bohunk's Airport (Private)	OCL6	2410	735	34° 41.7'	118° 17.0'
Oceanside	OCN	28	9	33° 14.4'	117° 25.0'
Ontario Airport	ONT	943	287	34° 03.3'	117° 36.1'
Reference Point #1	R1	4000	1219	34° 25.6'	117° 34.5'
Reference Point #2	R2	3400	1036	34° 30.2'	117° 54.6'
Reference Point #3	R3	2400	732	34° 39.6'	118° 19.6'
Riverside Airport	RAL	816	249	33° 57.1'	117° 26.6'
Santa Barbara Airport	SBA	10	3	34° 25.6'	119° 50.4'
San Gabriel Res.	SGR	2000	610	34° 14.0'	117° 50.4'
Simi Valley	SIM	400	122	34° 18.0'	118° 50.0'
Soggy Lake	SL	2800	853	34° 27.0'	116° 41.5'
Santa Monica Airport	SMO	175	53	34° 00.5'	118° 27.4'
San Pedro Point	SPP	0	0	33° 44.2'	118° 17.1'
Santa Paula Airport	SZP	245	75	34° 20.8'	119° 03.7'
Van Nuys Airport	VNY	799	244	34° 12.5'	118° 29.3'

4. DATA PROCESSING, FORMATS, AND AVAILABILITY

4.1 DATA PROCESSING

Data documentation began before take-off and continued throughout each flight. During a flight, the sampling instrumentation and the DAS were run continuously. A flight consisted of a sequential series of sampling events that included zeroing instruments before takeoff and after landing, spirals, traverses, and dolphins. These sampling events (excluding instrument zeroing) were called "passes" and were numbered sequentially from the beginning of each flight, starting at one. Each flight was processed as a series of passes.

Aboard the aircraft, the on-board scientist (instrument operator) controlled an event switch that was used to flag passes. The data flag was recorded by the DAS and used during data processing steps to identify various sections of data.

During each flight, the operator filled out standardized flight record sheets (flight notes) that summarized each pass; an example flight record sheet is shown in **Figure 4-1**. During data processing, the information contained in the flight notes was checked against the flags and other data that were recorded by the DAS.

Initial processing of the data began after the aircraft returned to the Camarillo base at the end of a sampling day. The objective was to provide a quick review of the data and to identify and correct problems if they existed. The following processing was performed in the field:

- The sampling date, the sampling period (start- and end-times), and the Zip disk identification number were determined from flight notes and compared with the information recorded on the data disk. Differences were reconciled and corrected before other processing steps were initiated.

- The contents of the data disk from the aircraft were copied to the hard drive of the on-site data processing computer. The original data disk was then archived.

- During sampling, the real-time sensor data were written to the DAS's hard drive and to a Zip removable disk (backup) in a space-saving binary file format. This format had to be decoded and then written into an ASCII text file format. A decoding program was used to converted the binary file into a "raw" (as recorded) voltage file and into a separate "raw" engineering unit data file. The newly created voltage and engineering unit files were stored on the hard drive of the processing computer.

16:20

SCOS97 — ***Flight Record Sheet*** — **STi**

Date: 8/6/97

Flight #: 7 - 2PM

Operator: JLL

Sheet 3 of 7

Pass #		4	5	6
Event Type (circle one)		S T D (D circled)	S T D (S circled)	S T D (D circled)
Start Time		13 30 : 23	13 49 : 54	14 0[illegible]:22
Stop Time		13 49 : 43	14 0[illegible] : 12	14 16:08
PASS ALTITUDE	START	1500	7500	2300
	STOP	7560 *	2300	7500*
END POINTS	START	L67	BNG	BNG
	STOP	BNG	BNG	L22
ALTIMETER				
INSTRUMENT RANGE	$NO\text{-}NO_y$	50 100 200 (200 circled)	50 100 200 (200 circled)	50 100 200 (200 circled)
	$NO1\text{-}NO_w$	50 100 200 (200 circled)	50 100 200 (200 circled)	50 100 200 (200 circled)
	O_3	200 500 (500 circled)	200 500 (500 circled)	200 500 (500 circled)

GRAB SAMPLES	Pass 4 Can	Pass 4 Bag	Pass 4 Can	Pass 4 Bag	Pass 5 Can	Pass 5 Bag	Pass 5 Can	Pass 5 Bag	Pass 6 Can	Pass 6 Bag	Pass 6 Can	Pass 6 Bag
Sample #					26	6						
Start Time					1357:52	1357:52						
Stop Time					1359:52	1359:52						
Start ALT					3500	3500						
Stop ALT					2500	2500						

COMMENTS	Pass 4	Pass 5	Pass 6
	* No power [illegible] highest Possible. Plane heavy + Air hot	7500 49 7000 47 6500 45 6000 49 5500 50 5000 47 4500 59 4000 61 Mixing to 4K	7500* highest possible.

Figure 4-1. An example of a flight record sheet.

- The decoding program generated QC values (flags) that were added to the engineering unit file and accompanied each measurement value through all remaining processing steps. Initially these QC flag values were set to zero by the decoding program, indicating each data point was valid. If later editing changes were made to a data point, the associated QC flag was automatically changed to reflect the editing that was performed.

- The decoding program also produced a summary of times at which the event switch (recorded by the DAS) was activated or changed. This file was called an event summary file.

- The status of the event switch (from the event summary) was compared to the instrument operator's written flight notes, and discrepancies were noted. Appropriate corrective actions were taken.

- The aircraft field manager reviewed each recorded parameter of the raw engineering unit data using the on-screen display function of an editing program.

- Preliminary comments regarding the data were relayed to the SCOS management team the day after a flight. In some cases, preliminary plots of the raw data were produced and forwarded as well.

- Copies of the aircraft data file, the converted raw voltage file, the converted raw engineering unit file, and flight notes were returned to STI for further processing.

At STI the following processing was performed:

- Review and interactive editing of the raw engineering unit data were performed using an editing program. One element of the editing program was the creation (and continual updating) of a separate log file that documented each processing step and logged all corrections that were made.

- The data were reviewed for outliers (typically due to aircraft radio transmissions). These outliers were marked using the editor and then invalidated.

- The editing program was used to add three calculated data fields to the flight data. Altitude in m msl (based on altitude in ft msl), absolute humidity (based on temperature, dew point, and pressure), and "HNO_3" (based on the difference between NO_y and NO_w measurements) data fields were added. Each data field had a QC field associated with it. If later editing changes were made to a base measurement, the editing program automatically updated the calculated data field and its QC flags.

- The type of sampling (spiral, traverse, or dolphin) performed during a pass and the location of the sampling (three-letter identifier) were added to the data file using the editing program.

- Using the event summary and flight notes, a tabular sampling summary was produced for inclusion with the data from each flight. **Figure 4-2** is an example of a sampling summary that can be found in the data report.

- A flight route map was produced for each flight (see examples in Section 3). Each sampling location was identified using the three-letter identifier that had been added to the magnetic media file during processing.

- Instrument calibration data were reviewed, and calibration factors were selected. Pre- and post-flight instrument zero values were checked and compared to calibration values.

- The editing program was used to apply zero values, calibration factors, offsets, and altitude correction factors (when appropriate) to the raw engineering unit data. Each correction or adjustment was automatically recorded in the editing program log file, and QC flags were changed appropriately.

- At this point, preliminary data plots were produced.

- Using the preliminary data plots, flight maps, sampling summaries, processing notes, and flight notes, a data processing system review was performed.

- Dates, times, locations, and the type of sampling for each pass were checked and cross-checked for each of the various outputs. The plotted data for each measurement were reviewed, and relationships between parameters (e.g., NO/NO_y ratios, etc.) were examined.

- Problems that existed were corrected. Most problems detected were clerical in nature (wrong end point number on the sampling summary, etc.) and were easily corrected. In one case, a flight needed to be reprocessed due to a parameter that had been mistakenly invalidated.

- After all editing had been completed, final data plots were produced.

- After completion of all processing and editing, the final engineering unit data were copied to permanent storage media (CD-ROM).

SCOS-97 Aircraft Data

STI Aircraft Sampling Summary

Sampling Date: 6-August-97
Aircraft ID: N6670Y

Flight Number: 7

Flight Route: Riverside, CA (RAL) to Camarillo, CA (CMA)
Northern Domain & SoCAB (Afternoon; Northern Domain)
(See sampling map)

Pass #	Pass Type *	Time (PST)		Altitude (m-msl)		Sampling Location**		INTEGRATED SAMPLING: VOC SAMPLING DETAILS					CARBONYL SAMPLING DETAILS				
								VOC ID #	Time (PST)		Altitude m-msl		Bag/ CARB. ID#	Time (PST)		Altitude m-msl	
		Start	End	Start	End	Start	End		Start	End	Start	End		Start	End	Start	End
1	S	12:56:01	13:09:09	249	1524	RAL	RAL										
2	D	13:09:36	13:19:15	1524	2286	RALL	L67H										
3	S	13:19:44	13:30:11	2286	457	L67	L67										
4	D	13:30:19	13:49:42	457	2304	L67L	BNGH										
5	S	13:49:56	14:00:11	2286	701	BNG	BNG	26	13:57:52	13:59:52	1067	762	6/A43	13:57:52	13:59:52	1067	762
6	D	14:00:21	14:16:06	701	2286	BNGL	L22H										
7	S	14:16:21	14:24:43	2286	975	L22	L22										
8	T	14:27:59	14:38:57	1372	1372	L22	SL										
9	T	14:39:04	14:56:51	1372	1372	SL	R1										
10	D	14:57:00	15:04:25	1372	2286	R1L	HESH										
11	S	15:04:47	15:12:55	2286	1067	HES	HES	112	15:10:07	15:12:17	1372	1067	2/A16	15:10:07	15:12:17	1372	1067
12	T	15:15:41	15:27:43	1372	1372	HES	R2										
13	T	15:27:45	15:37:39	1372	1372	R2	R3										
14	S	15:44:53	15:55:06	2286	759	OCL6	OCL6	111	15:52:15	15:54:15	1128	823	3/A19	15:52:15	15:54:15	1128	823
15	D	15:55:09	16:12:34	759	1524	OCL6	VNYH										
16	S	16:12:52	16:20:49	1524	290	VNY	VNY										
17	D	16:20:55	16:37:58	250	1219	VNYL	CMAH										
18	S	16:38:09	16:47:59	1219	23	CMA	CMA										

* *S = Spiral, O = Orbit, D = Dolphin, T = Traverse*
** Sampling locations for dolphins end with the letter "L" or "H". The "L" denotes the low point of the dolphin and "H" the high point.

Comments:
All "Dolphin" passes were plotted as if they were spirals.
Passes 4-7 were scheduled to sample up to (or down from) 2438 meters. But, the aircraft was not able to climb to this altitude (full fuel and heat).
Transport of pollutants out of the basin and into desert areas is evident in the data collected during passes 9-15. This transport was also observed by the flight crew.
Smoke from a large fire, affected the ozone data recorded during sampling in the Camarillo area (passes 17 and 18).

Figure 4-2. An example of a sampling summary contained in the data report.

4.2 DATA FORMATS AND AVAILABILITY

The continuous real time sensor data have been reported to the ARB in the three-volume data report by Anderson et al., 1998. The report contains a separate section for each flight. Each section contains a sampling summary such as the one shown in Figure 4-2. The summary details the sampling locations, times, and information concerning the sampling that was performed. The summary also shows sample identifiers, locations, times, and altitudes for each integrated VOC and carbonyl grab sample collected. A sampling route map (such as those in Section 3 of this report) follows the summary page. **Figure 4-3** is an example of a data plot; data plots follow the sampling route maps in the data report.

The data plots present "snapshot" views for each pass of a flight. Some portions of data (e.g., while the aircraft was repositioning for the next pass) were not plotted, but these data are contained in the digital data files that were delivered to the ARB. To increase the legibility of plotted data, selected averaging was performed. However, none of the magnetic media data are averaged.

The magnetic media data were delivered to the ARB in an uncompressed format on a CD-ROM. The CD is entitled "The real-time measurement data collected aboard the STI aircraft during SCOS97 sampling." The data files contained on the CD are in a tab-delimited text file format compatible with DOS-based computers. Each variable occupies one column, with columns separated by tab characters. The chosen format allows the user to read the data with both commercial software (e.g., spreadsheets such as MS Excel and word processors such as WordPerfect) or custom-programmed software (e.g., FORTRAN-based programs).

Five copies of the data report and CD were delivered to the ARB. Copies of the final processed data, individual log files, the original data from the aircraft, and processing notes are stored in archive files at STI. These archives will be maintained for at least five years.

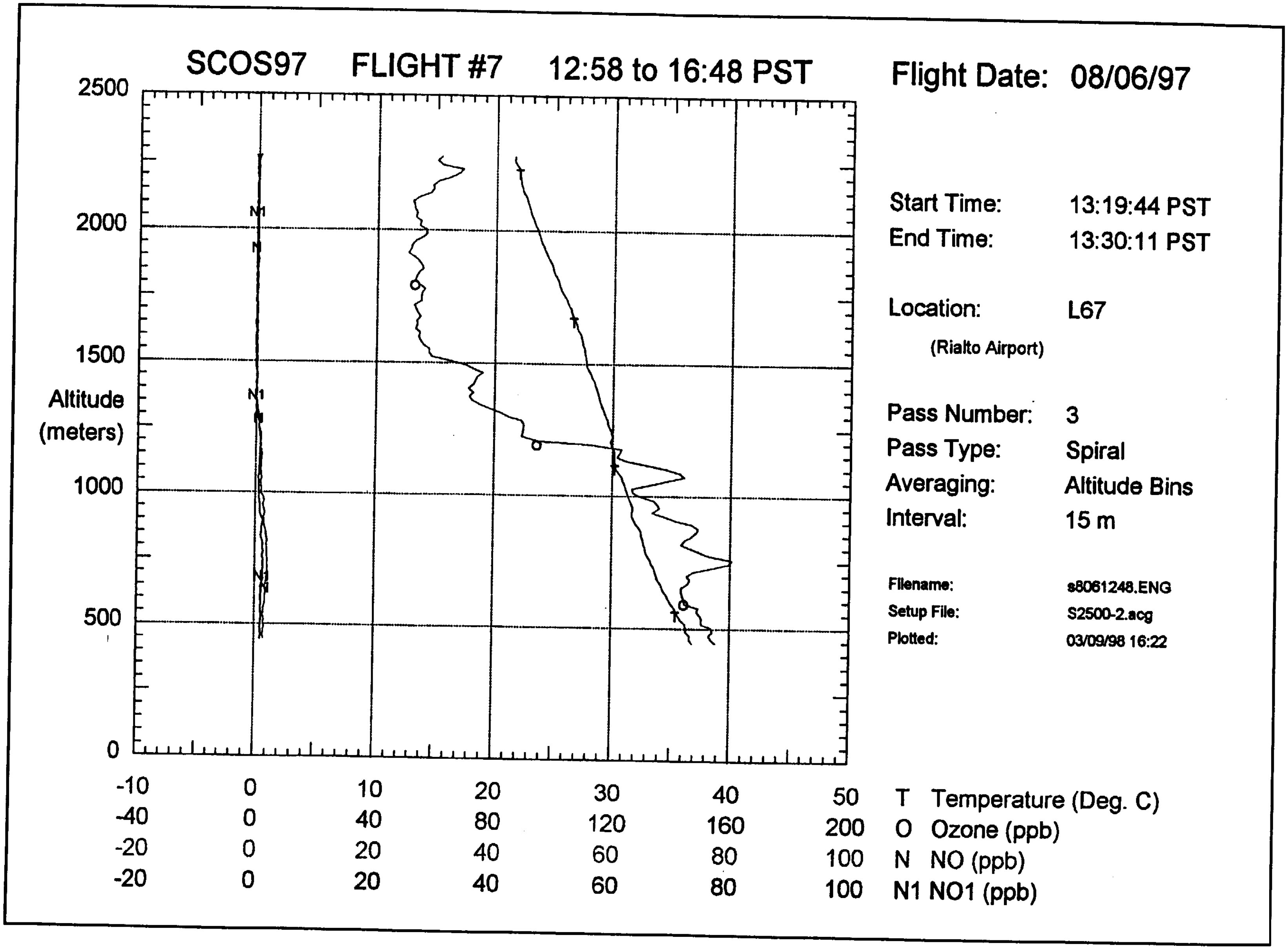

Figure 4-3. An example of a data plot included in the data report.

5. DATA QUALITY

Quality Control (QC) procedures are discussed in this report in terms of activities ***performed by STI*** to assure the quality of the aircraft data. ***Actions taken by others*** to assure the quality of the aircraft data are discussed as Quality Assurance (QA) activities. For example, instrument calibrations were an STI QC activity. But, the performance audit by the ARB was a QA activity as was the system check preformed by CE-CERT.

5.1 QUALITY CONTROL

5.1.1 Pre-program Quality Control Measures

The following activities were performed by STI before the start of the program to control the quality of the aircraft data:

- Checklists and log sheets, specific to the instruments and sampling systems operated aboard the aircraft, were designed. These were used throughout the program to standardize operational procedures and to document all activities relating to the measurements. A copy of the checklist used aboard the aircraft is included in Appendix A.

- A highly experienced staff was selected to perform the aircraft operations. The pilot had flown similar programs since 1987. The Program Manager and Instrument Operator had a combined total of more than 40 years experience in field programs involving air quality sampling and more than 30 years experience in airborne air quality sampling programs.

- Operational bases at the Camarillo and Riverside airports were established. Arrangements were made to install needed power circuits at each facility.

- Prior to ferry to Camarillo, each piece of sampling equipment to be used aboard the aircraft was cleaned, checked, and calibrated. New inlet particulate filters and sample lines were installed in the sampling instruments.

- The aircraft was instrumented and a test flight was flown. Data recorded during this flight were processed and reviewed to ensure that the complete instrumentation package (as a system) was operational.

- The calibration system and ozone transfer standard (UV photometer) were checked and certified. NIST-certified calibration gas was ordered and delivered to the Camarillo base facility.

- Aircraft sampling routes were discussed with the FAA and other airport facilities to ensure that desired sampling could be performed. Necessary certifications and waivers were obtained from the FAA.

- A performance audit of the gas monitors (while mounted in the aircraft) was performed on June 9 and 10, 1997. The audit results are described in Section 5.2.

- An inter-comparison flight was flown with the UCD aircraft.

- An inter-comparison flight was flown with the U.S. Navy aircraft.

5.1.2 Quality Control Measures During the Field Program

Many checks, procedures, and instrument backups combined to assure the quality of the aircraft data. They are listed below:

- Backup instruments (ozone and NO/NO_y) were maintained at the aircraft operation's base. These instruments were calibrated once, operated continuously, and were ready to be installed in the aircraft, when needed.

- After arriving in Camarillo, a short test flight was flown to ensure that sampling systems were still operational.

- At the Camarillo base, air conditioning was provided to the aircraft to reduce heat loading between flights or IOPs.

- Instruments requiring warm-up periods were turned on after arriving in the field and were operated continuously throughout the remainder of the program in order to maintain their calibrations. When the aircraft landed at the Riverside airport, the necessary power, hangar, and air conditioning was available to the instrumentation while the aircraft was between flights.

- All sampling coordinates were entered into the GPS unit aboard the aircraft. The entries were verified by a second person.

- The NO/NO_y and NO_1/NO_w sample inlets were cleaned at the end of each sampling day.

- Inlet particle filters were changed periodically throughout the program. Fixed instrument ranges were used for the continuous monitors throughout the sampling program.

- System checks of the aircraft sampling systems were conducted each day and prior to and following scheduled/completed flights.

- Multi-point calibrations of the air quality instruments were performed prior to and following most flight days. Additional details and the results of these calibration activities are reported in Section 5.1.3.

- To detect systematic calibration errors, the instruments were calibrated by different members of the aircraft crew on different days.

- A detailed checklist (see Appendix A) was used to perform extensive operational checks on each instrument prior to each sampling flight.

- Data were recorded on the data acquisition computer's hard disk drive and on a removable hard disk (ZIP drive) simultaneously to provide redundancy. Data were also printed on a small printer aboard the aircraft to provide a non-magnetic media backup of the data.

- The aircraft field manager debriefed flight crews after each flight to identify and, if necessary, correct any operational problems.

- Data files and flight notes were copied after each flight. Normally data processing was initiated within a couple of hours after the last flight of the day. The data were carefully reviewed by the aircraft field manager to identify any problems. Problems that were noted were discussed with the flight crew(s).

- After a flight was completed, flight notes were reviewed and VOC and carbonyl grab samples were inventoried and then delivered to CE-CERT personnel.

- After a carbonyl grab sample had been collected, the sample bag was placed inside a larger opaque bag.

- After the completion of the sampling program, the gas monitors aboard the aircraft were subjected to a system check performed by CE-CERT.

5.1.3 Calibration

After the aircraft arrived in Camarillo, power was connected to the NO/NO_y, the NO_l/NO_w, and the ozone monitors, and they were allowed to stabilize. Initial multi-point calibrations were performed using the calibration system described below. The instruments were typically calibrated before and after each flight day for the remainder of the program. All calibrations performed on the continuous instrumentation were full multi-point calibrations. Calibration results are shown in **Table 5-1**.

Once during the program, the primary ozone monitor experienced a power supply failure that was detected during the September 27, 1997 calibration. The instrument was replaced during the calibration with the backup monitor. The primary monitor was repaired and returned to service before the September 30, 1997 inter-comparison flight with the Navy aircraft.

Roughly half of the NO/NO_y data were lost during the morning flight of September 28, 1997, and all of its afternoon data were lost when the instrument's PMT cooler failed. The backup monitor was prepared, calibrated, and installed aboard the aircraft after completion of the afternoon flight.

Table 5-1. Summary of calibration results.

Date	Ozone		NO		NO_y			NO_1		NO_w		
	Slope	R^2	Slope	R^2	Slope	R^2	Con. Eff.	Slope	R^2	Slope	R^2	Con. Eff.
06/09/97	1.006	1.0000	0.999	1.0000	1.003	1.0000		0.999	1.0000	1.001	1.0000	
07/08/97	1.010	0.9999	1.002	0.9999	1.004	0.9999		0.996	1.0000	1.001	1.0000	
07/13/97	1.072	1.0000	1.117	0.9985	1.089	0.9994		1.046	0.9987	1.028	0.9994	
07/14/97	1.043	1.0000	1.071	0.9999	1.072	0.9999	100.0	1.024	0.9998	1.029	0.9998	100.0
07/23/97	1.029	1.0000	1.004	1.0000	1.004	1.0000		1.000	0.9998	1.004	0.9999	
07/29/97	1.036	1.0000	0.985	0.9996	0.985	0.9997		0.997	0.9999	0.999	0.9999	
08/03/97	1.065	1.0000	1.046	0.9885	1.049	0.9834	100.3	1.083	0.9728	1.076	0.9685	99.6
08/04/97	1.098	1.0000	1.069	0.9998	1.088	0.9998	99.6	1.066	0.9994	1.074	0.9996	99.0
08/05/97	1.095	1.0000	1.079	0.9999	1.102	0.9999		1.077	0.9994	1.084	0.9992	
08/06/97	1.087	1.0000	1.085	0.9998	1.109	0.9998		1.034	0.9997	1.043	0.9998	
08/07/97	1.092	1.0000	1.101	0.9999	1.131	0.9998	100.2	1.100	0.9998	1.104	0.9998	98.7
08/15/97	1.070	1.0000	1.018	1.0000	1.024	0.9999		1.080	1.0000	1.082	1.0000	
08/18/97			1.011	0.9999	1.018	0.9999		1.013	1.0000	1.015	0.9999	
08/21/97	1.091	1.0000	1.006	0.9995	1.008	0.9994		1.015	1.0000	1.014	1.0000	
08/23/97	1.117	1.0000										
09/03/97	1.030	1.0000	1.005	0.9999	1.042	0.9999		1.003	0.9998	0.984	0.9998	
09/04/97	1.033	1.0000	0.952	0.9999	0.981	0.9998	100.7	1.067	0.9997	1.045	0.9996	99.2
09/05/97	1.027	1.0000	0.933	0.9996	0.951	0.9997	104.9	1.041	0.9996	1.022	0.9996	91.7
09/06/97	1.036	1.0000	1.052	0.9998	1.077	0.9999	100.0	0.977	0.9999	0.945	0.9998	97.9
09/17/97	1.028	1.0000										
09/27/97	1.090	0.9997										
09/28/97	1.073	0.9999	1.106	1.0000	1.144	0.9999		0.974	0.9999	0.975	1.0000	
09/29/97	1.013	1.0000	1.095	0.9996	1.119	0.9996		0.948	0.9999	0.952	0.9999	
09/30/97	1.021	1.0000	1.067	0.9980	1.138	0.9998		0.955	0.9995	0.960	0.9994	
10/02/97	1.058	1.0000	1.178	0.9998	1.208	0.9999	102.3	0.948	1.0000	0.951	1.0000	99.0
10/03/97	1.033	1.0000	1.123	0.9999	1.143	0.9999		1.059	1.0000	1.061	0.9999	
10/04/97	1.044	0.9999	1.125	0.9996	1.148	0.9997	99.6	1.056	0.9999	1.060	0.9999	98.8
10/15/97	1.047	1.0000										
10/16/97			1.007	0.9999	1.023	0.9999		1.084	0.9999	1.088	0.9999	

Calibration equipment

The dynamic calibration system consisted of a portable calibrator, a zero air system/module (ZAM), an ozone transfer standard, and a NIST-traceable gas cylinder containing a nominal concentration of about 25.06 $\pm$.25 ppm NO and 25.06 ppm NO_x in O_2-free nitrogen. The calibrator contained two mass flow controllers which provided known flow rates of dilution air from the ZAM and span gas from the standard gas cylinder. The calibrator was capable of delivering the desired gas concentrations by adjusting each mass flow controller to provide previously determined flow rates. The dilution airflow controller had a nominal range of 1,000 to 10,000 standard cubic centimeters per minute (sccm), and the span gas flow controller had a nominal range of 5 to 100 sccm.

The calibrator contained an ozone generator, which was used for O_3 calibrations. The ozone stream could be directed into the dilution air stream to enable these calibrations. Gas-phase titration (GPT) could also be performed by directing the ozone stream into the NO span gas stream. The calibrator had a reaction chamber and a mixing chamber of appropriate dimensions, which, when taken together with the flow rates that were used, complied with the U.S. Environmental Protection Agency (EPA) requirements for NO_2 generation by means of the GPT procedure.

As required by the EPA, high concentration span gases came in contact with only stainless steel, Teflon, and glass. Diluted gases came in contact with only Teflon and glass, and were sampled from the calibrator at ambient pressure by means of a small sample manifold, to which the calibrator effluent and analyzer sample line were connected.

Zero air module

Zero air for the calibrator was generated from ambient air using a portable ZAM. The ZAM contained a compressor, a drier, Purafil, activated charcoal, Hopcalite, and a 5-micron molecular sieve particle filter. The ZAM delivered dry air, which was free of NO, NO_2, and O_3, at a flow and pressure which met the specifications of the dilution mass flow controller in the calibrator.

Compressed gas standard

The NIST-traceable NO span gas cylinder used during the project was purchased from Scott-Marrin, Inc. This cylinder was used with the dilution calibrators to calibrate the NO/NO_y and the NO_1/NO_w analyzers.

Ozone transfer standard

A Dasibi 1003 was used as a transfer standard. It was traceable to a primary standard and was certified using the primary standard. During calibration, ozone concentrations generated by the calibrator were measured using the transfer standard.

Procedures

The calibrator and transfer standard were checked and tested in a QA laboratory in Camarillo prior to use on the program. Mass flow controllers received multi-point flow checks. The ozone transfer standard was certified against a primary standard before the program and then again after the program.

For ozone calibration, the sample delivery line from the calibrator was connected to the inlet of the glass manifold inside the aircraft. The analyzer sampled normally from the glass manifold. Temperature (in the photometer cell) and pressure measurements were made during calibrations and were applied to calculations to determine true ozone concentrations.

For calibration of the two NO analyzers, the sample nozzles were removed and a Teflon line was used to interconnect the two inlet systems. The sample delivery line from the calibrator was then connected to what was normally the exhaust port of one of the inlet systems. The analyzers sampled normally from their inlet system. Following most multi-point calibrations, a converter efficiency check was performed on each monitor using standard GPT methods.

5.2 QUALITY ASSURANCE AUDITS

As part of the overall QA plan for the project, an audit of the gas analyzers aboard the aircraft was performed by personnel from the Quality Assurance Section of the ARB. The audit (June 9 and 10, 1997) was performed at the Camarillo hangar facility. After completion of the audit, preliminary results were reported to STI by Watson and Warren, 1997. Final audit results, shown in **Table 5-2**, were reported by Miguel, 1999.

ARB's warning limits for gaseous analyzers are ±10% and their control limits are ±15%. The results shown in the table are well within the warning limits.

Good airflow past aircraft temperature and dewpoint temperature sensors is required to obtain representative readings. Since this was not possible while the aircraft was in the hangar, these sensors were not audited by the ARB.

A comparison check of the nitrogen oxide monitors was performed by CE-CERT on October 17, 1997 after completion of sampling. CE-CERT has expressed the preliminary opinion (Bumiller, 1998) that NO, NO_y, NO_1, and NO_w values reported by STI during the comparison all appeared to be within ±6 percent when compared to CE-CERT standards. CE-CERT also stated that ozone values reported by the STI monitor compared well to their standard.

Table 5-2. Final audit results reported by the ARB for instruments audited aboard the STI aircraft during the June 9 and 10, 1997 performance audit.

	Audit Concentration (ppb)	Percent Difference*	Average Percent Difference	Standard Percent Difference	Correlation	Converter Efficiency (%)
NO/NO_y (Audit results for NO_2)	47	-6.4				
	66	-4.5				
	133	-1.5				
			-4.1	2.5	0.99999	100.1
NO_t/NO_w (Audit results for NO_2)	47	-6.4				
	67	-6.0				
	134	-3.7				
			-5.4	1.4	0.99997	99.04
Ozone	70	-5.0				
	177	-4.8				
	394	-5.5				
			-5.1	0.3	0.99999	

$$* \text{ Percent Difference} = \frac{\text{Station Response - Audit Concentration}}{\text{Audit Concentration}}$$

5.3 RESULTS OF THE INTER-COMPARISON FLIGHTS

A document by DRI entitled "SCOS97-NARSTO Volume IV: Summary of Quality Assurance" (Fujita et al., 1998) reported the details of the inter-comparison flights of the STI and UCD aircraft. The following comments have been excerpted and edited from the DRI report or are based on data in the report.

- "During the traverse from [Azusa] to Cable [airport], UCD and STI aircraft generally flew next to each other at approximately 1100 m msl." DRI noted that "recorded altitudes show[ed] generally less than 50 m differences between [the two aircraft] with the UCD altitudes being slightly higher." They also noted that "the two temperature profiles were very similar with an offset of about 2°C" between the two aircraft (UCD was higher). "Measurements of nitrogen oxides...were very similar between UCD and STI. However, UCD measurements show[ed] a number of sharp spikes with a one-to-one correspondence between NO and NO_2 spikes neither of which appeared in the STI data." DRI concluded that the "...difference could have been due to different time resolution of STI and UCD instruments," but they also noted that "...such spikes did not appear in other [UCD measurement data.]" Ozone comparisons could only be made for about the last minute of the traverse. The UCD aircraft reported ozone concentrations 10 to 20 ppb lower than STI values.

- "During the return flight from Cable to El Monte [airport], the altitude was about 2000 m msl. The altitudes [were] within 100 m and UCD temperatures were again a couple of degrees higher than STI's. Ozone measurement[s] compared very well with maximum differences around 15 ppb, similar features, and STI generally measuring slightly higher values." The nitrogen oxide measurements compared quite well between the aircraft though the UCD data again had spikes. DRI suggested that "...the possibility of measurement artifacts should be considered."

- Both aircraft performed a spiral down – spiral up comparison at the Cable airport. For the STI aircraft, DRI concluded that "the agreement between ascending and descending ozone measurements [was] reasonable (i.e., within 15 ppb) with the ascending spiral showing more structure and lower ozone concentrations." During spirals at the Cable airport, the UCD aircraft followed (2 minutes behind) the STI aircraft during the downward and then the upward spirals. UCD also measured lower ozone concentrations during their ascending spiral.

- The two aircraft also performed a spiral down – spiral up comparison at the El Monte airport. DRI noted that "the qualitative structures... for the [STI] ascending and descending spirals were quite similar." However, the ascending spiral's main feature, an ozone peak at about 1050 m msl (about 97 ppb), was at a higher altitude than the peak recorded during the descending spiral at about 900 m msl (about 94 ppb). DRI suggested that "the peak shift could possibly [have been] due to a measurement delay," but they noted that "the temperature data for these two spirals show[ed] a hysteresis effect very similar to the ozone data." They concluded that "the differences between the ozone data measured for the two spirals were partly caused by atmospheric differences."

- During the descending spirals at El Monte, each of the two aircraft measured an ozone peak at about the same altitude (roughly 900 m msl), though the UCD peak value was about 20 ppb higher than the STI recorded value. During the lowest 400 m or so of the spirals, the agreement between the two aircraft was good, although the STI ozone data values were about 10 ppb higher than the UCD data values.

- While the two aircraft were performing ascending spirals at El Monte, CE-CERT released an ozonesonde, and NOAA operated their ozone lidar. The ozonesonde, lidar, and STI aircraft all reported an ozone peak at about 1050 m msl. The ozonesonde and STI reported this peak to be roughly 97 ppb. The lidar peak concentration was about 78 ppb. The UCD aircraft reported a peak of about 80 ppb at roughly 950 m msl.

- A comparison of STI/UCD/ozonesonde temperature data during the ascending aircraft spirals at El Monte showed that each recorded similar atmospheric structures. About a 1.5°C to 2°C difference between aircraft measurements (UCD was higher) existed throughout the comparison range of the spiral. At the surface, the STI temperature was roughly 25.4°C, UCD was roughly 27.8°C, and the ozonesonde recorded roughly 29.7°C. Above the first couple of hundred meters of the surface, the STI temperatures nearly matched those reported by the ozonesonde.

At the time of preparation of this report, the U.S. Navy had not reported data collected during their inter-comparison flight with the STI aircraft. During the flight, the data acquisition system computer aboard the Navy plane was malfunctioning. The computer's clock was not producing a reliable time base, and the computer reset multiple times during the flight. Thus, the Navy may not be able to produce a data set that could be used for comparative purposes.

5.4 COMPARISON OF AIRCRAFT AND SURFACE OZONE DATA

Aircraft data were compared to surface ozone data as an additional control check. For comparisons of aircraft and surface ozone data to be meaningful, the aircraft and surface stations should be measuring the same airmass. To minimize compounding factors in the comparison, the surface measurements should be made near the aircraft sampling location, and the aircraft measurements should be made close to the surface. In addition, good mixing conditions ensure a more uniform air mass.

Only two aircraft spiral sites were close enough to surface air quality sites to satisfy the above criteria. Ozone measurements during afternoon sampling (spirals) at the Riverside and Banning airports and the existence of nearby surface monitoring sites satisfied the criteria. At the Hesperia Profiler site, the aircraft was not able to sample low enough to provide meaningful comparisons. At other aircraft spiral locations, surface sites were judged to be too far from the aircraft spiral location for useful comparisons.

Surface ozone measurements are made at Mira Loma, UC Riverside, and Rubidoux. These sites surround the Riverside airport - all are within 6 to 10 km of the airport. During Northern Boundary afternoon sampling missions, the aircraft took off from the Riverside airport. Thus, aloft ozone measurements from the surface upward were recorded at the airport location.

A surface monitoring site is located at the Banning airport. During sampling at Banning, the aircraft spiraled down to a low pass along the runway. Typically the low pass was made to within 10 m or so of the surface.

To derive surface values, hourly ozone values for each surface station were determined for periods corresponding to aircraft sampling. If the aircraft's sampling spiral extended across two hourly surface reporting periods (e.g., 1258-1309 PST on August 6, 1997 at the Riverside airport), the two reported hourly surface values (for 1200 and 1300 PST) were averaged for each surface site. To determine a regional average for the Riverside area, the resulting (averaged when necessary) data for each of the three nearby stations were averaged together.

Average ozone concentrations for the lowest 25 m of the appropriate aircraft spirals were determined. The resulting surface and aircraft data are shown in **Table 5-3**. The table shows the date, sampling period, and ozone values measured by the aircraft at the Riverside and Banning airports. The surface reporting period (or periods) used and the hourly ozone value (or averaged value) for each surface site are included in the table. The regional average (representative of the Riverside airport sampling location) is shown in the right column of the table.

Table 5-3. The data used to compare aircraft ozone data to surface site ozone measurements.

Date	Aircraft Sampling Period (PST)	Aircraft Sampling Location	Aircraft Ozone Values (ppb)	Surface Hourly Reporting Period(s) (h PST)	Surface Site Ozone Values (ppb)				Riverside Region Average Ozone [b] (ppb)
					BANN	MRL	UCR	RUB	
4-Aug-97	1403-1421	Riverside	84	14	-	-	100	97	98.5
5-Aug-97	1309-1320	Riverside	162	13	-	180	-	150	165.0
5-Aug-97	1357-1409	Banning	64	13,14 [a]	70	-	-	-	-
6-Aug-97	1258-1309	Riverside	128	12,13 [a]	-	135	145	132.5	137.5
6-Aug-97	1350-1400	Banning	76	13	80	-	-	-	-
22-Aug-97	1407-1417	Riverside	68	14	-	90	70	73	77.7
23-Aug-97	1308-1315	Riverside	114	13	-	110	130	113	117.7
23-Aug-97	1351-1406	Banning	74	13,14 [a]	80	-	-	-	-
4-Sep-97	1407-1417	Riverside	120	14	-	100	120	105	108.3
5-Sep-97	1357-1407	Riverside	109	13,14 [a]	-	95	115	98	102.7
6-Sep-97	1256-1306	Riverside	106	12,13 [a]	-	95	105	92.5	97.5
6-Sep-97	1344-1354	Banning	58	13	60	-	-	-	-
28-Sep-97	1307-1317	Riverside	54	13	-	90	60	49	66.3
29-Sep-97	1257-1306	Riverside	98	12,13 [a]	-	80	105	83.5	89.5
3-Oct-97	1356-1406	Riverside	65	13,14 [a]	-	75	75	67	72.3

[a] Values listed for the surface site(s) are the average of both reporting hours.

[b] The Region average is the average of the MRL, UCR, and RUB values shown in the table.

The comparison of the aircraft and surface ozone data is shown in **Figure 5-1**. The Riverside data are shown as filled diamonds and the Banning data as open diamonds. The regression line was calculated for all points. The agreement between the aloft and surface measurements is very good. It is interesting to note, however, that the STI aircraft data seem to report slightly less ozone than the surface stations. This is consistent with the ARB audit results (Table 5-2) that show that the aircraft ozone monitor might have under-reported ozone values by a small amount.

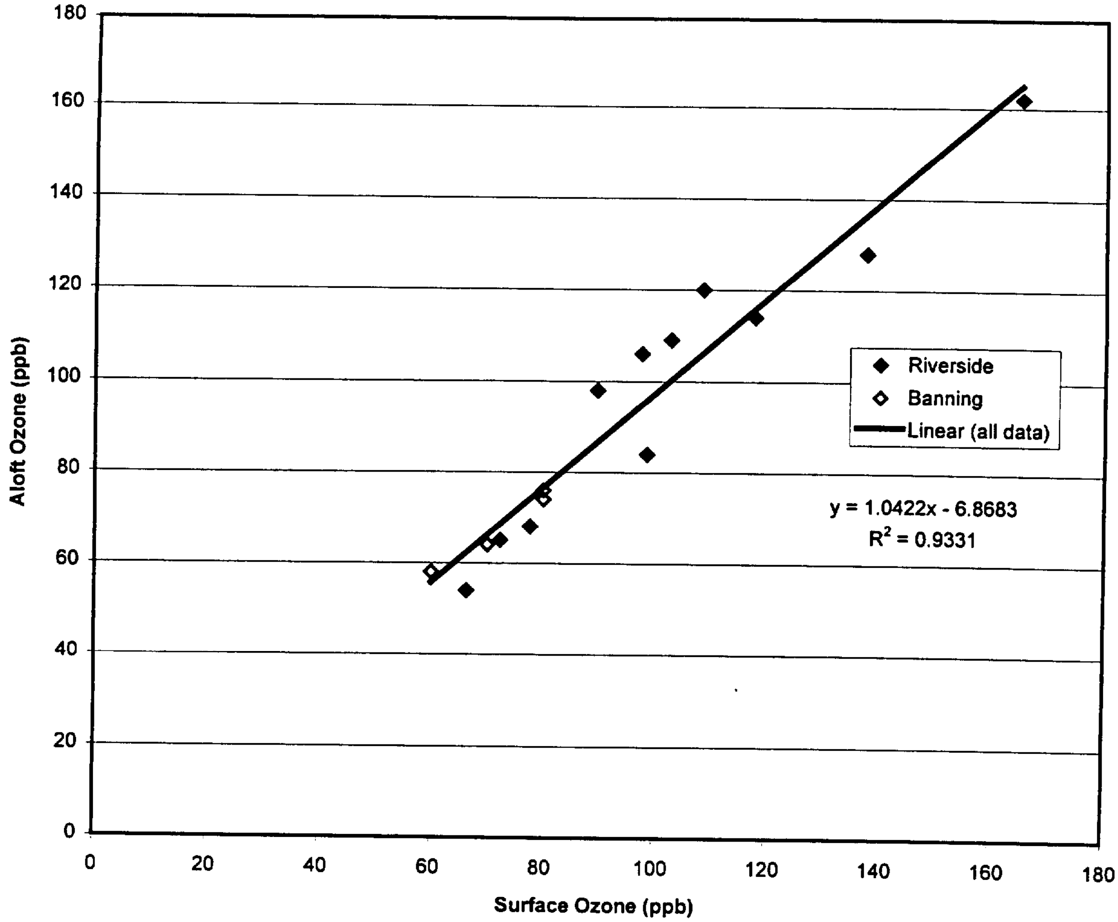

Figure 5-1. A comparison of STI aircraft ozone data and surface ozone data. Riverside surface values are composite averages of the Mira Loma, UC Riverside, and Rubidoux ozone data.

The good agreement between the aircraft and surface data is especially encouraging given that the aircraft data are instantaneous while the surface data are due to the hour averages. This indicates that, at least in the afternoon, the aircraft data should be useful for comparison with model results which have 1-h resolution.

6. DISCUSSION OF ELEVATED LAYERS AND USES OF AIRCRAFT DATA

A major objective of the STI airborne measurements was to provide data to be used to investigate the processes that result in the formation of high ozone concentrations in layers aloft and to estimate the effect of those layers on surface concentrations at later times. This section describes typical processes for formation of high ozone concentrations aloft, and discusses some implications of the layers and how monitoring data can be used to assess the causes of ozone aloft and its contribution to surface concentrations. The importance of obtaining information on elevated layers for model input and evaluation as well as for other uses is also discussed.

Much of the literature on elevated layers in the Basin is listed in the draft SCOS97 Field Plan (Fujita et al., 1996). Additional information is available from numerous other field study reports such as Blumenthal and Ogren, 1976; Keifer et al., 1979; Smith et al., 1983; Blumenthal et al., 1986; Anderson et al., 1989; Main et al., 1991; Main et al., 1993; Roberts and Main, 1992; Roberts et al., 1993; Carroll and Dixon, 1997; and Smith et al, 1997.

One of the dominant causes of layering is wind shear, when air at the surface is moving faster or slower than air aloft and often in a different direction. Under wind shear conditions, the surface and aloft air masses can have different temperatures and densities; and mixing between the air masses can be limited by density/temperature gradients, with the warmer air aloft. Undercutting by the sea breeze is a good example of this process. This undercutting in Los Angeles was shown by Blumenthal et al. (1978). In the Los Angeles Basin, the cool sea breeze starts in midmorning and is typically lower than the subsidence inversion over the Basin. Pollutants that have mixed to the inversion during the morning are undercut by fresher air when the sea breeze penetrates to the San Gabriel Valley.

The pollutants that are trapped above the sea breeze and below the subsidence inversion are free to react without ozone depletion by fresh NO emissions; and thus ozone can reach higher concentrations than at the surface. The elevated layer is also exposed to more sunlight and is warmer than the air below, additionally accelerating the formation of ozone in the layer. In the absence of nearby injection into the layer of buoyant stack emissions, the pollutants in the elevated layer tend to be well aged, with low toluene to benzene or propene to acetylene ratios and low NO_x. In these layers, the NO_x typically has reacted to form PAN, nitric acid, and other nitrates. The aged nature of the air in the layers is characteristic of most of the layer formation processes.

Another major cause of layering in the South Coast Basin is the formation of radiation inversions at night, especially in the inland valleys. Pollutants that are mixed to the subsidence inversion during the day are typically undercut at night by the formation of low-level surface-based inversions. Pollutants emitted at the surface during the night and early morning are confined near the surface. Ozone and aged pollutants aloft can easily last all night at high concentrations, undepleted by fresh emissions, and are available to be transported to downwind air basins or to be mixed to the surface the next morning as the surface mixing layer deepens (Blumenthal et al., 1980). An example of early morning carryover at Rialto is shown in **Figure 6-1** from measurements by STI in 1992 (Anderson et al., 1993).

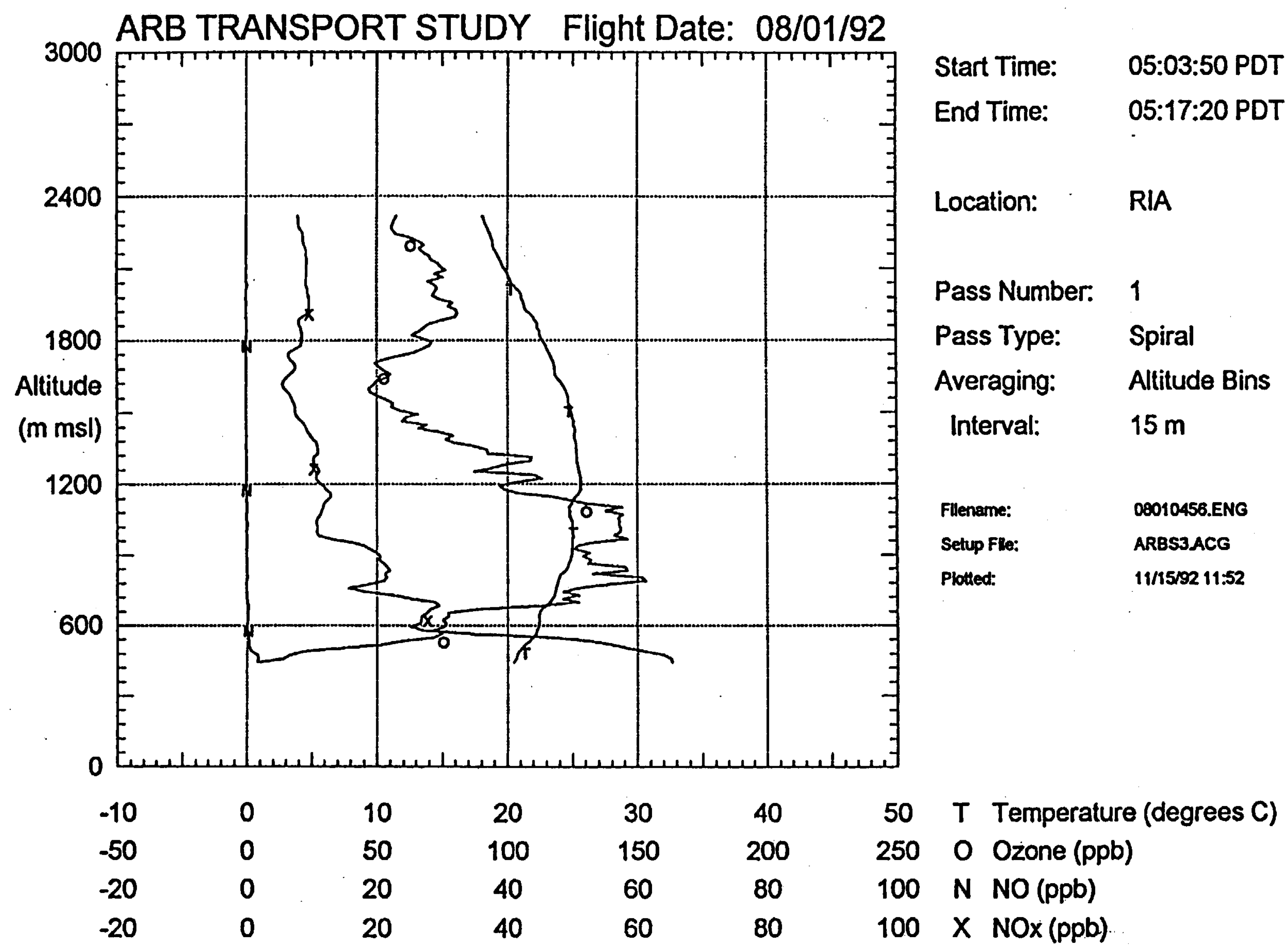

Figure 6-1. Early morning spiral over Rialto on August 1, 1992 (Anderson et al., 1993).

Slope flows and conversion zones can also generate elevated layers. Heated slopes draw air upslope to an altitude where further rise is limited by stability or by lack of further heating. At that elevation a layer can be formed. Along the San Gabriels, if the aloft flow is northerly, these layers can move back over the Basin. In our experience however, these layers are usually confined near the mountains. If the air above the subsidence layer is not stable, upslope flows act as a ventilation mechanism. Generally during episodes, however, even the air above the subsidence inversion is stable.

Slope flows can loft pollutants to an altitude above the subsidence inversion. **Figure 6-2** is a photograph taken in the eastern Los Angeles Basin during SCAQS showing pollutants trapped below the subsidence inversion with elevated layers near the mountains separated from the surface layer by cleaner air. This is an example of layers formed by slope flow. Under these conditions, it is unlikely that the air in the layer would subsequently mix to the surface to affect surface concentration; unless the subsidence inversion breaks, in which case the surface layer would be ventilated.

Convergence zones, such as near Lake Elsinore, tend to act as ventilation mechanisms, lofting pollutants to high elevations. However, if one air mass is cooler than the other, or the air aloft is quite stable, a layer can be formed, with the cooler air mass undercutting the warmer one.

Buoyant plumes can also contribute to the formation of elevated layers. In general, plumes rise to a height where they are limited by stability. To contribute to a layer, the plumes must be prevented from being mixed to the surface. The limiting stability that creates a layered plume comes from the same mechanisms that form the elevated layers discussed above. Thus plumes tend to contribute to layers that are already formed by other means. In coastal areas, plumes can mix with pollutants that are pushed up the slopes or trapped aloft by the sea breeze. As shown in **Figure 6-3**, we have documented the same-day transport of these layers to the north toward Ventura County with ozone concentrations of almost 350 ppb (Blumenthal et al., 1986). These plumes can impact the coastal mountain slopes or be brought to the surface if they move inland along the Oxnard Plain. Similar layers might also be transported south to San Diego.

As noted above, layers can also be formed by a combination of mechanisms.

The elevated layers are important for several reasons. Over the Basin, they provide a reservoir of high-concentration aged pollutants which can be mixed to the surface on the next day. The effect of this mixing is to accelerate the ozone formation on the second day. In effect, as the mixing layer deepens, the surface-based pollutants are mixed with high concentrations of ozone instead of being diluted with clean air. It is important to understand the spatial extent of these layers to understand their importance for surface concentrations in the Basin and downwind.

Layers can also impact the mountain slopes along the San Gabriel and San Bernardino Mountains (McElroy and Smith, 1993) or along the coast. The coastal layers can be transported north or south on the same day or overnight, and can be mixed to the surface as they move inland in Ventura or San Diego Counties. In these situations, the layers could cause exceedances directly if their ozone concentrations are high enough.

Figure 6-2. Photo of elevated layers due to upslope flow over the San Gabriel Mountains during SCAQS.

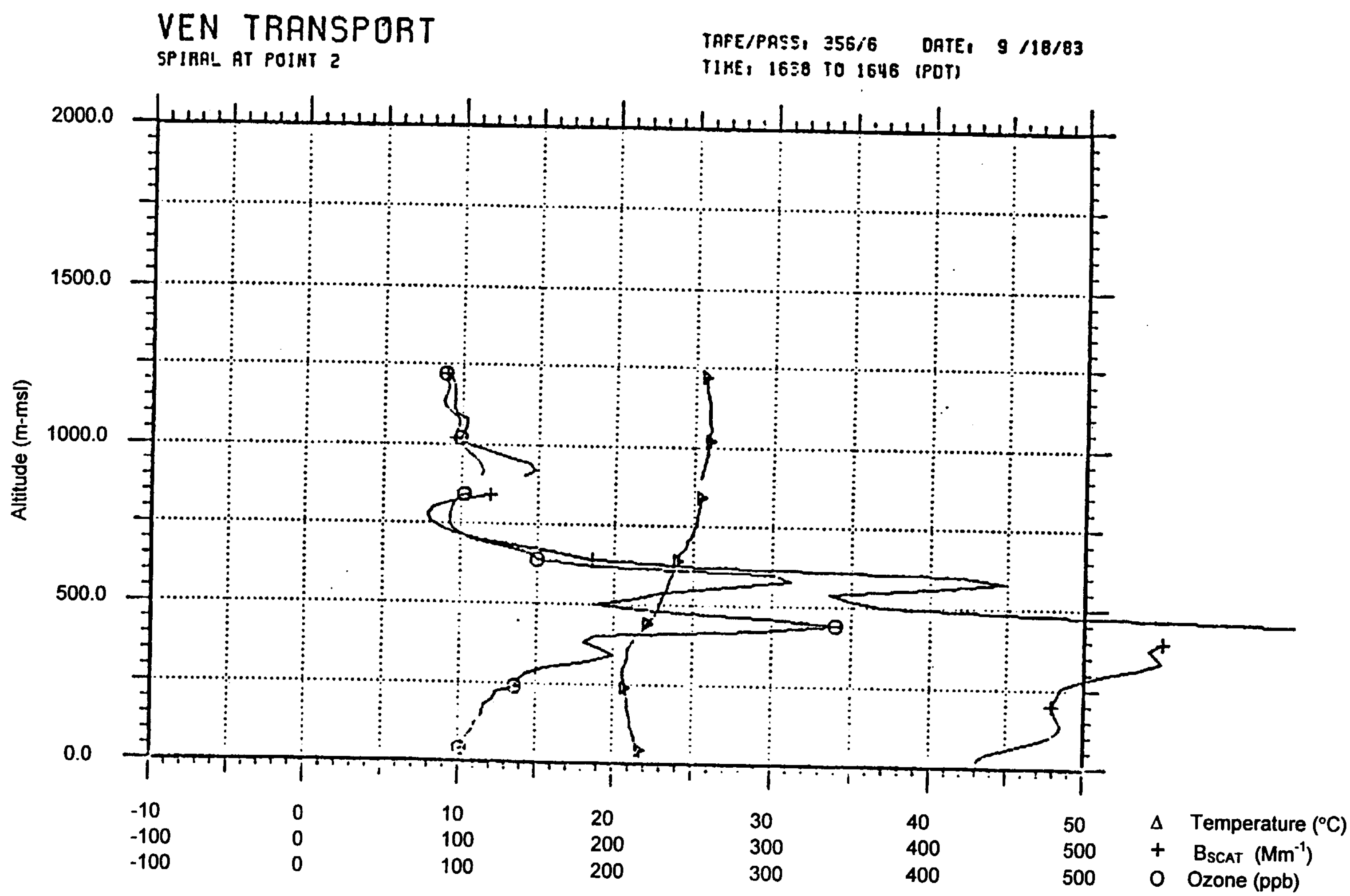

Figure 6-3. Spiral offshore of Laguna peak at 1538 PST on September 18, 1983 (Blumenthal et al., 1986).

The layers can cause high-concentration upper boundary conditions over the study area. The chemistry of this upper boundary is typically well aged compared to the fresher emissions near the surface. If models do not simulate the layers or take into account the high boundary concentrations, it is hard to have confidence that they are predicting correct surface concentrations for the right reasons.

The use of the monitoring data to assess the causes and role of aloft layers as well other uses of the aircraft data are partially described in Section 8 of the SCOS97 Field Plan (Fujita et al., 1996). The plan also summarizes prior uses of three-dimensional data and describes some of their limitations in Section 2. The topics discussed in the plan include:

- Examining the vertical distribution of concentrations from airborne measurements.
- Determining horizontal transport patterns and intensities into, out of, and within the air basins.
- Determining vertical transport patterns and intensities within the modeling domain.
- Characterizing the depth, intensity, and temporal changes of the mixed layer, including mixing of elevated and surface emissions.
- Characterizing pollutant fluxes.
- Estimating the fluxes and total quantities of selected pollutants transported across flux planes.
- Evaluating boundary conditions for models.

These analyses contribute to the refinement of conceptual models of how the layers form and their importance for surface-level ozone.

The aircraft data by themselves can be used to document the existence of the layers and provide boundary conditions at specific times; but with only two or three flights per day, they are not sufficient to show how the layers form or mix to the surface. To fully understand the processes at work, it is necessary to combine the aircraft data with continuous or frequent vertical measurements of winds and ozone concentrations.

For SCOS97, there were continuous ozone measurements at El Monte Airport, four/day ozonesondes at several locations, radar profilers with RASS at over 20 locations, and some sodars and rawinsondes. The aircraft flight plans were designed to be complementary to these measurements. The continuous ozone measurements documented the formation and mixing to the surface of ozone layers. The wind measurements allow testing of hypotheses regarding undercutting and upslope flows as well as the transport of layers. The RASS measurements and sodar measurements can be used to document the formation and erosion of stable layers. The aircraft measurements documented the chemistry of the layers and can be used to identify the role of fresh emissions (e.g., upslope transport or elevated plumes) versus aged reactants in the layers. The aircraft data also provide information on the spatial extent of the layers, the gradients between surface-based sites, and the characteristics of the layers offshore.

In conjunction with the upper-air wind information, the aircraft data can support estimates of fluxes and inter-basin transport.

The upper-air data are essential for the evaluation of models. As noted earlier, it is necessary for the models to properly simulate the upper-air phenomena in order to have confidence that the models are predicting the right concentrations for the right reasons. The aircraft data can be used to develop conceptual models as well as to provide data for direct comparison with model results. As shown by Roberts et al. (1993), the models currently in use tend to underestimate the concentrations and importance of the elevated layers.